

Module description

for the degree programme

Bachelor of Science

Autonomy Technologies

(Version of examination regulation: 20242)

for the winter term 2025/2026

Table of contents

Mathematics I (62765).....	7
Mathematics II (62767).....	9
Mathematics III (62769).....	11
Electrical engineering I (92315).....	13
Electrical engineering II (92316).....	15
Algorithms, programming, and data representation (92313).....	16
System-level programming (92328).....	20
Machine learning for engineers I - Introduction to methods and tools (95067).....	22
Introduction to MATLAB (92317).....	24
Electric drives (92321).....	27
Signal Theory (92323).....	29
Mechatronic components and systems (MCS) (92347).....	31
Sensors (92322).....	33
Stochastic processes (92324).....	34
Digital signal processing (92325).....	36
Introduction to Communication Systems (92326).....	38
Dynamical Systems and Control (47603).....	40
Modeling of Control Systems (92241).....	42
Machine Learning for Control Systems (94967).....	43
Embedded Systems (44411).....	44
Numerics for engineers I (92329).....	47
Simulation of autonomous systems (92331).....	48
Laboratory course: Electrical engineering and automation (92314).....	49
Human-system interfaces - Core modules	
Human-centered mechatronics and robotics (92345).....	51
Robot mechanisms and user interfaces (92359).....	53
Human computer interaction (645618).....	55
Intent detection and feedback (47616).....	58
Human-system Interfaces - Specialization modules	
Image and video compression (96310).....	61
Image, video, and multidimensional signal processing (92343).....	63
Body area communications (816185).....	66
Human-robot co-adaptation (47623).....	68
Rehabilitation and assistive robotics (47617).....	70
AI in medical robotics (93101).....	72
Robotics in surgery and diagnostics (47708).....	74
Surgical Technologies Innovation (44159).....	76
Human-system Interfaces - Seminar & laboratory	
Laboratory course Human-Robot Interaction (92507).....	79
Seminar: Autonomous systems and mechatronics (92346).....	81
Seminar: Human-robot interaction (47667).....	82
Seminar: The why and how of human gait simulations (47595).....	83
Networking & Collaboration - Core modules	
Digital communications (47800).....	85
Information theory and coding (48410).....	87
MIMO communication systems (96300).....	90
Machine learning in communications (668129).....	92
Networking & Collaboration - Specialization modules	
Image and video compression (96310).....	94
Communications systems design (700506).....	96

Cyber-physical systems (636348).....	98
Mobile communications (43141).....	100
Multiuser information and communications theory (687141).....	102
Random matrices in communications and signal processing (451971).....	104
Channel coding on graphs (412023).....	106
Advanced communication networks (151664).....	109
Convex optimization in communications and signal processing (96850).....	113
Transmission and detection for advanced mobile communications (43420).....	115
Approximate computing (965820).....	118
Next Generation Mobile Communication Systems: 5G-Advanced and 6G (96065).....	120
Networking & Collaboration - Seminar & laboratory	
Laborpraktikum Multimediakommunikation (97651).....	123
Laboratory course: Digital signal processing (92335).....	125
Seminar: Selected topics of multimedia communications and signal processing (92336).....	127
Smart city: Technologies and systems (92337).....	129
Joint communications and sensing in wireless systems (92527).....	131
Laboratory course: Mobile communication (97640).....	133
Laborpraktikum Digitale Signalverarbeitung (97520).....	136
Smart City: Technologies and systems (TuS) (92361).....	138
Digital communication Lab (93511).....	140
Planning & Control - Core modules	
Robotics 1 (92519).....	145
Nonlinear control systems (92529).....	146
Numerical optimization and model predictive control (92528).....	148
Introduction to deep learning (43405).....	150
Planning & Control - Specialization modules	
Robotics 2 (92535).....	153
Control engineering B (State-space methods) (97060).....	155
Digital control (97360).....	158
Estimation Methods for Control Systems (94961).....	160
Ereignisdiskrete Systeme (92430).....	161
Statistical signal processing (96430).....	163
Machine learning in signal processing (48440).....	165
Pattern analysis (44120).....	167
Pattern recognition (44130).....	169
Reinforcement learning (93185).....	171
Fundamentals of robotics (94951).....	173
Robotics frameworks (92880).....	175
Distributed systems (95280).....	177
Advanced topics in deep learning (42800).....	180
Gait analysis and simulation+ (47575).....	182
Planning & Control - Seminar & laboratory	
Lab course machine learning in signal processing (878210).....	185
Legged locomotion of robots (LLR) (47656).....	187
Sensing & Perception - Core modules	
Radar, RFID and wireless sensor systems (RWS) (96316).....	189
Statistical signal processing (96430).....	191
Image, video, and multidimensional signal processing (92343).....	193
Machine learning in signal processing (48440).....	196
Sensing & Perception - Specialization module	
Image and video compression (96310).....	199
Computational visual perception (93173).....	201

Radar signal processing (44400).....	203
Advanced optical communication systems (621649).....	206
Waveguides, optical fibres and photonic crystal fibres (67145).....	208
Perception in robotics (42801).....	210
Speech and Language Processing (44455).....	212
Transforms in signal processing (498723).....	214
Linear and non-linear fibre optics (267499).....	216
Computer vision (713618).....	218
Sensing & Perception - Seminar & laboratory	
Laborpraktikum Multimediakommunikation (97651).....	221
Laboratory course: Image and video signal processing on embedded systems (92344).....	223
Laboratory course: Digital signal processing (92335).....	225
Lab course machine learning in signal processing (878210).....	227
Seminar: Wireless, radar and microwave techniques (92373).....	229
Seminar: Selected topics of multimedia communications and signal processing (92336).....	231
Laboratory architectures for digital signal processing (182405).....	233
Laborpraktikum Digitale Signalverarbeitung (97520).....	235
Seminar on selected topics of multimedia communications and signal processing (914949).....	237
Laboratory course: Image and video signal processing on embedded platforms (97525).....	239
Laboratory course: Sensor technology (97690).....	241
Technical elective module	
Power electronics for decentralized energy systems (42919).....	243
Transport processes (43700).....	246
Test integrierter Schaltungen (44000).....	247
Legged locomotion of robots (LLR) (47656).....	250
Legged locomotion of robots + laboratory project (LLR-L) (47657).....	251
Game theory with Applications to Information Engineering (48432).....	253
Introduction to machine learning (65718).....	255
E-Learning: PC skills (86681).....	258
Communication networks (92290).....	259
Design of mobile sensor systems and nodes (92357).....	261
Optical communication systems (92400).....	263
Basics of optoelectronic components (92502).....	265
Numerical methods for semiconductor components (92503).....	266
Semiconductor technology II - Process and component simulation (HLT II) (92514)...	267
Semiconductor technology VI - Flexible electronics (HL VI) (92526).....	269
Implementation of database systems (93020).....	271
Fundamentals of metrology (94510).....	274
Industry 4.0 - Application scenarios in production and service (94946).....	283
Industrial test applications for integrated circuits and systems (94963).....	285
Seminar on safety critical circuit design issues (94965).....	287
Radar remote sensing with satellites (94966).....	289
Power storage systems (94969).....	290
Power storage systems (94971).....	292
Medical engineering I (biomaterials) (95801).....	294
Antennae (96000).....	296
Architectures for digital signal processing (96010).....	298
Medical electronics (96030).....	300
HF-Schaltungen und Systeme (96220).....	302

Operating materials and components for electrical energy supply systems (96511)....	304
Analog-Digital- und Digital-Analog-Umsetzer (96740).....	306
Communication structures (96801).....	308
Multiphysics systems and components (96841).....	310
Laboratory course: Design of Integrated Circuits I (96842).....	312
Advanced topics in perceptual audio coding (96875).....	313
Auditory models (96885).....	315
Music processing - Analysis (96890).....	316
Practical introduction to machine learning (96940).....	319
Technical product design (97110).....	320
Quality management (97246).....	325
Laboratory: Digital ASIC design (97500).....	327
Laboratory course: Systematic design with programmable logic devices (PLD) (97720).....	330
Wireless automotive electronics (92539).....	332
Fields and waves in optoelectronic components (V-Fel-Wel) (96313).....	334
Signal conditioning in analogue integrated circuits (46930).....	336
Secure Systems (93105).....	338
Numerics for engineers I (64620).....	340
Automotive engineering (95340).....	341
Business administration for engineers (BW 1 + BW 2) (999823).....	343
Packaging technologies for power electronics (118154).....	344
Electrical railways (123620).....	347
Microwave Measurements (145947).....	349
Real-time systems with extended exercises (179490).....	351
Reliability of technical systems (244966).....	356
Signal analysis (250058).....	358
Control of vehicle powertrains (432733).....	360
Transforms in signal processing (498723).....	362
Design-for-Test (542026).....	364
Medical imaging systems (800224).....	366
Modeling, optimization and simulation of energy systems (858896).....	368
Dependable real-time systems (lecture with exercises) (876012).....	369
Radar, RFID and wireless sensor systems (RWS) (96316).....	372
Image, video, and multidimensional signal processing (92343).....	374
Image and video compression (96310).....	377
Computational visual perception (93173).....	379
Radar signal processing (44400).....	381
Advanced optical communication systems (621649).....	384
Waveguides, optical fibres and photonic crystal fibres (67145).....	386
Robotics 1 (92519).....	388
Nonlinear control systems (92529).....	389
Numerical optimization and model predictive control (92528).....	391
Introduction to deep learning (43405).....	393
Control engineering B (State-space methods) (97060).....	395
Robotics 2 (92535).....	398
Digital control (97360).....	400
Estimation Methods for Control Systems (94961).....	402
Ereignisdiskrete Systeme (92430).....	403
Statistical signal processing (96430).....	405
Machine learning in signal processing (48440).....	407
Pattern analysis (44120).....	409
Pattern recognition (44130).....	411

Reinforcement learning (93185).....	413
Fundamentals of robotics (94951).....	415
Robotics frameworks (92880).....	417
Distributed systems (95280).....	419
Digital communications (47800).....	422
Information theory and coding (48410).....	424
MIMO communication systems (96300).....	427
Machine learning in communications (668129).....	429
Communications systems design (700506).....	430
Cyber-physical systems (636348).....	432
Mobile communications (43141).....	434
Multiuser information and communications theory (687141).....	436
Random matrices in communications and signal processing (451971).....	438
Channel coding on graphs (412023).....	440
Advanced communication networks (151664).....	443
Convex optimization in communications and signal processing (96850).....	447
Transmission and detection for advanced mobile communications (43420).....	449
Approximate computing (965820).....	452
Human-centered mechatronics and robotics (92345).....	454
Robot mechanisms and user interfaces (92359).....	456
Human computer interaction (645618).....	458
Intent detection and feedback (47616).....	461
Body area communications (816185).....	463
Human-robot co-adaptation (47623).....	465
Rehabilitation and assistive robotics (47617).....	467
AI in medical robotics (93101).....	469
Advanced topics in deep learning (42800).....	471
Perception in robotics (42801).....	473
Robotics in surgery and diagnostics (47708).....	475
A look inside the human body - gait analysis and simulation (96837).....	477
Gait analysis and simulation+ (47575).....	479
Introduction to Cybersecurity Fundamentals in Networking (93074).....	481
Fundamentals in anatomy and physiology for engineers (47664).....	483
Speech and Language Processing (44455).....	484
Surgical Technologies Innovation (44159).....	486
Seminar: The why and how of human gait simulations (47595).....	488
Linear and non-linear fibre optics (267499).....	489
Computer vision (713618).....	491
Security in embedded hardware (172338).....	493
Localization Systems for IoT (92736).....	495

1	Module name 62765	Mathematics I	7,5 ECTS
2	Courses / lectures	Vorlesung: Mathematics for Engineers I (4 SWS) Übung: Exercise Mathematics for Engineers I (2 SWS)	- -
3	Lecturers	Prof. Dr. Giovanni Fantuzzi Dr. Lorenzo Liverani Dr. Shigenori Nakatsuka	

4	Module coordinator	apl. Prof. Dr. Wilhelm Merz
5	Contents	• Foundations: • logic, sets, relations, mappings • Number systems: • natural numbers; integers; rational, real and complex numbers • Vector spaces: • Foundations, linear dependence, span, basis, dimension, Euclidean vector space, subspaces, affine spaces • Matrices, linear maps, systems of linear equations: • Matrix algebra, structure of the solution sets of linear equations, Gauss algorithm, inverse matrix, types of matrices, linear maps, determinants, image and kernel, eigenvalues and eigenvectors, basis, least squares problems • Foundations of real analysis: • limits, continuity, elementary functions, inverse functions
6	Learning objectives and skills	Students learn: • fundamental terms and structures of mathematics • structure of the number system • certain handling of vectors and matrices • solution techniques for linear systems of equations • fundamentals of analysis and exact mathematical analytical methods
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 90 h Independent study: 135 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• W. Merz, P. Knabner: Mathematik für Ingenieure und Naturwissenschaftler, Lineare Algebra und Analysis in #. 1. Aufl., Berlin Heidelberg: Springer, 2013.

	• W. Merz, P. Knabner: Endlich gelöst! Aufgaben zur Mathematik für Ingenieure und Naturwissenschaftler, Lineare Algebra und Analysis in #. 1. Aufl., Berlin Heidelberg: Springer, 2014.

1	Module name 62767	Mathematics II	7,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	apl. Prof. Dr. Wilhelm Merz
5	Contents	• Calculus for functions of one real variable: • derivative with rules, mean value theorems, L'Hospital, Taylor's theorem, curve discussion • Integrals for functions of one real variable: • Riemann-Integral, Fundamental Theorem of Calculus, mean value theorems, improper integrals • Sequences and series: • real and complex sequences of numbers, convergence: definition and theorems, sequences and series of functions, uniform convergence, power series, Fourier series, iterative solution of nonlinear equations • Foundations of calculus for functions of several real variables: • limit, continuity, differentiation, partial derivative, total derivative, Taylor's theorem
6	Learning objectives and skills	Students learn: • skilful handling of differential and integral calculus • handling of mathematical models • convergence of sequences and series • computing of limits • basic properties of multidimensional functions
7	Prerequisites	None
8	Integration in curriculum	semester: 2
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%) •
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 90 h Independent study: 135 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• W. Merz, P. Knabner: Mathematik für Ingenieure und Naturwissenschaftler, Lineare Algebra und Analysis in #. 1. Aufl., Berlin Heidelberg: Springer, 2013.

	• W. Merz, P. Knabner: Endlich gelöst! Aufgaben zur Mathematik für Ingenieure und Naturwissenschaftler, Lineare Algebra und Analysis in $\mathbb{R}$. 1. Aufl., Berlin Heidelberg: Springer, 2014. • W. Merz, P. Knabner: Endlich gelöst! Aufgaben zur Mathematik für Ingenieure und Naturwissenschaftler, Analysis in $\mathbb{R}^n$ und gewöhnliche Differentialgleichungen. 1. Aufl., Berlin Heidelberg: Springer, 2017. • W. Merz, P. Knabner: Mathematik für Ingenieure und Naturwissenschaftler, Analysis in $\mathbb{R}^2$ und gewöhnliche Differentialgleichungen. 1. Aufl., Berlin Heidelberg: Springer, 2017.

1	Module name 62769	Mathematics III	7,5 ECTS
2	Courses / lectures	Übung: Exercise Mathematics for Engineers III (2 SWS) Vorlesung: Mathematics for Engineers III (4 SWS)	- -
3	Lecturers	Prof. Dr. Ricardo Correa da Silva	

4	Module coordinator	apl. Prof. Dr. Wilhelm Merz
5	Contents	• Application of calculus in $\mathbb{R}^n$: • Unconstrained optimization problems; constrained optimization problems; Lagrange multiplier rules; implicit function theorem; examples of applications; • Vector analysis: • Potential, volume integrals, surface integrals, line integrals, parametrization, transformation theorem, integral theorems, differential operators, • Ordinary differential equations: • analytical solution methods; existence and uniqueness of solutions; linear differential equations; systems of differential equations; eigenvalues of differential operators; generalized eigenvectors; fundamental systems; stability
6	Learning objectives and skills	Students learn: • extreme value determination in higher dimensions • identify significant differences compared to one dimensional optimization techniques • relationship between volume, surface and line integrals • knowledge of various differential operators • typing of ordinary differential equations • fundamental solution techniques • applications in engineering science
7	Prerequisites	None
8	Integration in curriculum	semester: 3
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 90 h Independent study: 135 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• W. Merz, P. Knabner: Mathematik für Ingenieure und Naturwissenschaftler, Lineare Algebra und Analysis in R. 1. Aufl., Berlin Heidelberg: Springer, 2013.

	• W. Merz, P. Knabner: Endlich gelöst! Aufgaben zur Mathematik für Ingenieure und Naturwissenschaftler, Lineare Algebra und Analysis in $\mathbb{R}$. 1. Aufl., Berlin Heidelberg: Springer, 2014. • W. Merz, P. Knabner: Endlich gelöst! Aufgaben zur Mathematik für Ingenieure und Naturwissenschaftler, Analysis in $\mathbb{R}$ und gewöhnliche Differentialgleichungen. 1. Aufl., Berlin Heidelberg: Springer, 2017. • W. Merz, P. Knabner: Mathematik für Ingenieure und Naturwissenschaftler, Analysis in $\mathbb{R}^n$ und gewöhnliche Differentialgleichungen. 1. Aufl., Berlin Heidelberg: Springer, 2017.

1	Module name 92315	Electrical Engineering I Electrical engineering I	7,5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Electrical Engineering I (4 SWS) Übung: Exercise Electrical Engineering I Tutorium: Tutorium EE1	7,5 ECTS - -
3	Lecturers	Prof. Dr.-Ing. Norman Franchi Torsten Reißland Maximilian Lübke Danial Dehghani Zahra Seifaei	

4	Module coordinator	Prof. Dr.-Ing. Norman Franchi
5	Contents	This lecture introduces the physical principles of electrical and electronic engineering. Electric and magnetic fields are taught after introducing the concept of observable force effects between charges and currents. With the derived integral quantities of voltage, current, resistance, capacitance, and inductance derived from these, the behavior of passive components is discussed. Using DC circuits as an example, the methods of network analysis are introduced, and questions of efficiency and interconnection of sources are examined. Emphasis is placed on Faraday's law of induction and its applications. Motion induction is considered in the context of three-phase generators, and quiescent induction is discussed in great detail using transformers and transformers as examples. The treatment of time-periodic processes is another focus. Complex AC calculus for sinusoidal current and voltage waveforms and Fourier analysis for time-periodic non-sinusoidal signals are treated in detail. 1. basic physical terms 2. the electrostatic field 3. the steady-state electric flow field 4. simple electrical networks 5. current conduction mechanisms 6. the stationary magnetic field 7. the time-varying electromagnetic field 8. alternating voltage and alternating current 9. time-periodic processes of arbitrary waveforms
6	Learning objectives and skills	Students are able to: 1. Understand the concept of fields 2. Develop DC and AC circuits with resistors, capacitors, inductors, and transformers 3. Analyze oscillating circuits and resonance phenomena 4. Perform energy and power calculations 5. Evaluate circuits for power matching and reactive current compensation 6. Understand the three-phase system.

7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 165 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 92316	Electrical Engineering II Electrical engineering II	7,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Roland Nagy
5	Contents	Electrical measurement technology Fundamentals of measurement Fourier transforms Laplace transforms Network analysis in time and Laplace domain Transfer function and Bode diagram Nonlinear components, circuits and systems Operational amplifiers Measuring amplifiers Measurement errors Measurement of direct current and direct voltage Deflection bridges Balancing bridges, measurement of electrical impedances
6	Learning objectives and skills	The students will learn to classify methods according to their suitability for specific problems (time/frequency domain, linear/nonlinear). They select and apply suitable methods for the analysis of electrical networks as well as interpret the results and show correlations between the solution methods. Moreover, fundamentals of operational amplifiers and measuring circuits are presented, preparing the students to analyze and apply them. This includes bridge circuits and the calculation of measurement errors. Students will independently reflect on their own learning outcomes.
7	Prerequisites	None
8	Integration in curriculum	semester: 2
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	no Module frequency information available!
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 92313	Algorithms, Programming, and Data Representation Algorithms, programming, and data representation	10 ECTS
2	Courses / lectures	Vorlesung: Algorithms, programming, and data representation (4 SWS)	5 ECTS
		Übung: Algorithms, programming, and data representation; Computer Exercise (2 SWS)	2,5 ECTS
		Übung: Algorithms, programming, and data representation; Exercise (2 SWS)	2,5 ECTS
3	Lecturers	Felix Nützel Prof. Dr. Bernhard Kainz	

4	Module coordinator	Prof. Dr. Bernhard Kainz
5	Contents	This module provides an introduction to computer science and programming, covering fundamental concepts and techniques. Students will develop a solid foundation in computer programming using the Python programming language. The module aims to foster independent learning and effective collaborative programming through practical work and problem-solving activities. Week 1: Motivation and Logistics, Introduction to Computers - This session sets the stage by discussing the motivation behind studying computer science and covers the logistics of the module. Week 2: Data Representation, Boolean Algebra, and Python Basics - Topics include data representation in computers, Boolean algebra, and an introduction to Python programming language. Students will learn about organization and basic operations in Python. Week 3: Memory Organization, Branching, and Control Statements - This week focuses on memory organization, branching, and control statements. Students will explore different number representations and continue learning about Boolean algebra. They will also delve into control statements, specifically if-else statements. Week 4: Decomposition, Functions, and Control Statements (Loops) - Students will learn about decomposition, abstraction, and functions. The session will cover topics such as tuples, lists, recursion, and dictionaries. Additionally, control statements related to loops will be discussed, and students will submit their solutions for mathematical operation questions. Week 5: Testing, Debugging, Exceptions, and Object-Oriented Programming - This week emphasizes the importance of testing, debugging, and handling exceptions. Students will gain an understanding of object-oriented programming concepts and how to implement them in Python. They will also explore advanced Python data types and submit their solutions for control statements (if-else) questions.

Week 6: Classes, Inheritance, Program Efficiency, and Debugging

- The session focuses on classes, inheritance, and program efficiency. Students will deepen their knowledge of recursion and learn about debugging techniques, including the use of try-except statements. They will submit solutions for debugging and try-except statements questions.

Week 7: Program Efficiency, Searching, and Sorting

- Topics covered include program efficiency optimization, searching algorithms, and sorting algorithms. Students will continue their exploration of object-oriented programming and submit their solutions for recursion questions.

Week 8: Version Management with Git and Object-Oriented Programming

- This week introduces version management using Git and emphasizes its importance in collaborative programming projects. Students will further enhance their understanding of object-oriented programming and submit their solutions for advanced Python data types questions.

Week 9: Trees and Searching

- The focus of this week is on trees, their representation, and searching algorithms. Students will also submit their solutions for searching and sorting questions.

Week 10: Graphs, Dijkstra's Algorithm, and Graph Algorithms

- Students will learn about graphs, graph algorithms, and specifically Dijkstra's algorithm for finding the shortest path in a graph. They will submit their solutions for Dijkstra's algorithm questions.

Week 11: Hashtables

- This session introduces hashtables as a data structure for efficient searching and retrieval. Students will gain practical knowledge of implementing hashtables.

Week 12: Revision and Q&A

- This week is dedicated to revising the covered topics and addressing any questions or concerns students may have.

Learning Goals and Competencies:

- Independent organization and coordination of own work
- Problem-solving and solution development in theoretical and programming tasks
- Quality assurance of submitted solutions
- Responsibility and evaluation of own work

By the end of this module, students will have a solid foundation in computer science, programming principles, and collaborative

		programming skills necessary for further studies and practical application of computer science concepts.
6	Learning objectives and skills	1. Understanding Computer Science and Programming Basics: - Acquire fundamental knowledge about computer science and programming. - Understand the motivation and logistics behind studying computer science. - Gain a preliminary understanding of computers and their components. 2. Proficiency in Python Programming Language: - Learn basic operations and organization in Python. - Comprehend and implement different data types in Python such as tuples, lists, dictionaries, etc. - Develop proficiency in control statements, branching, loops, and functions. - Understand and apply principles of object-oriented programming, classes, and inheritance in Python. - Learn about error handling and debugging in Python. 3. Learning about Memory Organization: - Understand how data is represented in computers. - Learn about memory organization, Boolean algebra, and different number representations. 4. Developing Problem-Solving Skills: - Solve mathematical problems using programming concepts. - Apply programming concepts to solve practical problems. - Learn how to search, sort, and apply algorithms to solve complex problems. - Implement searching algorithms in different data structures like trees, graphs, and hashtables. 5. Understanding and Implementing Version Control using Git: - Understand the importance of version management in collaborative programming projects. - Learn how to use Git for version management. 6. Mastering Debugging Techniques and Exception Handling: - Understand the importance of testing and debugging. - Learn about different debugging techniques and how to handle exceptions using try-except statements in Python. 7. Developing Independent Learning and Collaborative Programming Skills: - Cultivate the ability to organize and coordinate personal work independently. - Enhance problem-solving skills and solution development in theoretical and programming tasks.

		- Learn to assure the quality of submitted solutions and evaluate personal work. - Understand how to work in a collaborative programming environment. 8. Familiarity with Different Data Structures and Algorithms: - Learn about data structures like trees, graphs, and hashtables. - Understand different searching algorithms and sorting algorithms. - Learn about Dijkstra's algorithm for finding the shortest path in a graph. 9. Understanding Program Efficiency: - Gain knowledge about program efficiency and its optimization. - Learn about the application of recursion in improving program efficiency.
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Tutorial achievement Written examination (120 minutes) Graded examination achievement (Prüfungsleistung): Written examination (120 min) Ungraded course achievement (Studienleistung): weekly submission of exercises; at least 50% of total points required to pass
11	Grading procedure	Tutorial achievement (9%) Written examination (91%)
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• Guttag JV. Introduction to computation and programming using Python. MIT Press; 2013 Aug 9.

1	Module name 92328	System-level Programming System-level programming	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Rüdiger Kapitza
5	Contents	• Introduction to the C programming language: differences to Java, concept of modularity, pointers and pointer arithmetic • Software development on bare hardware (i.e., ATmega microcontroller): memory mapping, language constructs, interrupts, and concurrency • Software development on an operating system (i.e., Linux): operating system as execution environment for programs • Abstractions and services of an operating system: file systems, programs and processes, signals, threads, and synchronization
6	Learning objectives and skills	Students who have successfully completed the module are able to: 1. explain the basic elements of the C programming language: data types, operators, expressions, control structures, functions, variables, preprocessor. 2. evaluate C in comparison to Java in terms of syntax, idiom, and philosophy. 3. describe key differences in software development for a microcontroller platform compared to an operating-system platform. 4. present how pointers work. 5. detail the implementation of strings and string operations in C. 6. use specific language features of C for hardware-oriented software development and concurrent register accesses. 7. develop simple programs in C for a microcontroller platform (i.e., ATmega) both with and without library support. 8. develop simple programs for an operating-system platform (i.e., Linux) using POSIX system calls. 9. explain techniques of abstraction, functional decomposition, and modularization in C. 10. describe the steps from C program to executable binary code. 11. reproduce the basic operation of a processor with and without interrupt processing. 12. discuss variants of event handling on embedded systems. 13. use interrupts and power-saving states in the implementation of simple control units. 14. explain synchronization problems that occur (lost update, lost wakeup) and implement suitable counter-measures. 15. describe basic features of memory management on a microcontroller platform and an operating-system platform (stack structure, memory classes, segments, heap). 16. explain how a file system works.

		17. use the basic input/output operations from the C standard library. 18. distinguish the concepts of program and process, and describe process states. 19. use basic process operations (fork, exec, signal) from the C standard library. 20. explain the differences between processes and threads, and describe strategies for thread implementation on an operating system. 21. explain process-/thread-level coordination problems and basic synchronization abstractions (e.g., semaphore, mutex). 22. use the POSIX thread abstractions to implement multi-threaded programs.
7	Prerequisites	Basic knowledge of programming (independent of the programming language)
8	Integration in curriculum	semester: 2
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• Manfred Dausmann, Ulrich Bröckl, Dominic Schoop, et al. C as a first programming language: from beginner to advanced. Vieweg +Teubner, 2010. ISBN: 978-3834812216. • Brian W. Kernighan, Dennis M. Ritchie. The C Programming Language. Prentice Hall PTR, 1988. ISBN: 978-8120305960.

1	Module name 95067	Machine Learning for Engineers I - Introduction to Methods and Tools Machine learning for engineers I - Introduction to methods and tools	5 ECTS
2	Courses / lectures	Vorlesung: Machine Learning for Engineers I: Introduction to Methods and Tools (VHB) (4 SWS)	5 ECTS
3	Lecturers	Thomas Altstidl	

4	Module coordinator	Prof. Dr. Björn Eskofier
5	Contents	This is an introductory course presenting fundamental algorithms of machine learning (ML) that are typically applied to data science problems. Knowledge is deepened by two practical exercises to gain hands-on experience. The course covers • Introduction to Python programming in the field of data science • Review of typical task domains (such as regression, classification and dimensionality reduction) • Theoretical understanding of widely used machine learning methods (such as linear and logistic regression, support vector machines (SVM), principal component analysis (PCA) and deep neural networks (DNN)) • Practical application of these machine learning methods on engineering problems
6	Learning objectives and skills	After successfully participating in this course, students should be able to • independently recognize the task domain at hand for new applications • select a suitable and promising machine learning methodology based on their known theoretical properties • apply the chosen methodology to the given problem using Python
7	Prerequisites	None
8	Integration in curriculum	semester: 2
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination Electronic exam (online), 90min
11	Grading procedure	Written examination (100%)
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 0 h Independent study: 150 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	1) Machine Learning: A Probabilistic Perspective, Kevin Murphy, MIT Press, 2012

		2) The Elements of Statistical Learning: Data Mining, Inference, and Prediction, Trevor Hastie, Robert Tibshirani, and Jerome Friedman, Springer, 2009 3) Deep Learning, Ian Goodfellow, Yoshua Bengio, and Aaron Courville, MIT Press, 2016

1	Module name 92317	Introduction to MATLAB	2,5 ECTS
2	Courses / lectures	Praktikum: Introduction to MATLAB yes	2,5 ECTS
3	Lecturers	Dr.-Ing. Clemens Stierstorfer	

4	Module coordinator	Dr.-Ing. Clemens Stierstorfer	
5	Contents	An introduction to MATLAB using examples from school math and linear algebra. 1) Introduction to Matlab 2) Create Plots with Matlab 3) Properties of Matrices 4) Polynomials 5) Using the Symbolic Math Toolbox	
6	Learning objectives and skills	General Information The students learn how to use the software MATLAB to solve mathematical or engineering problems by means of examples given in the provided lab notes. In detail: • Students will distinguish between the different types of data in MATLAB and create variables for vectors or matrices; they will apply basic arithmetic operations to these variables. • Students create their own script files and design their own functions; they use loops, if statements, and branching, among other techniques. • They output mathematical functions of a variable graphically and apply interpolation tools. They use the possibilities of three-dimensional representation for functions of several variables. Likewise, they visualize complex-valued problems as they are common in electrical engineering. • Students solve systems of linear equations numerically with MATLAB and implement their own functions for this purpose; they calculate the eigenvalues and eigenvectors of matrices; they use Cayley-Hamilton's theorem for the efficient calculation of matrix powers. • Students evaluate polynomials numerically with MATLAB and implement their own functions for this purpose; they use MATLAB to calculate products and sums of polynomials and differentiate polynomials; they create their own functions for numerical zero search and approximate functions with polynomials; • Students solve systems of symbolic equations using MATLAB and perform a curve discussion using MATLAB or the associated "Symbolic MATH Toolbox"; they determine the surface area and volume of solids of revolution using MATLAB. Learning or methodological skills Students use MATLAB's online help to search for and clarify how to use MATLAB commands. They work their way independently into the topics	

		covered using the documentation provided and introductory literature on the mathematical topics. Self-competences The students recognize the necessity of the strictly regulated procedures of the lab course and organize their work accordingly (punctuality, mandatory attendance, preparation, documentation of results). They recognize the advantages of thorough preparation and consolidation of the contents of the experiments. The students already recognize possible subject-specific gaps during the preparation of the experiments at home and fill them independently. Social competences The students solve the assignments together, hand them in as a team before working on the experiments and solve the practical tasks together as a team in the computer room. They discuss the mathematical/program problems and present and explain the solutions as a team.
7	Prerequisites	A prerequisite for successful participation in the lab course is a solid command of school mathematics and the content of the mathematics lectures of the 1st semester of the bachelor's program. This refers in particular to the following areas: Analysis (curve discussion of functions of one variable, integration of functions of one variable), linear algebra (systems of equations, Gaussian elimination, eigenvalues), complex numbers (polar representation and coordinates).
8	Integration in curriculum	semester: 1
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement Which tasks have to be solved in the course? • There are 5 experiments to be completed. These are described in the course documents. • For each experiment there is a set of assignments that must be prepared in writing at home. • The solution of the assignments will be assessed at the beginning of each experiment (sufficient/not sufficient). • The prepared documents are to be archived electronically on StudOn before the start of the experiment. • The MATLAB code written in an experiment must be clearly written, structured and well documented. It will be reviewed verbally at the end of each experiment (sufficient/not sufficient). No additional written documentation is required. • The files with the MATLAB code have to be uploaded to StudOn by the end of the day of the experiment. What is necessary to pass the course? • To pass the lab course, five homework assignments graded as sufficient and five experiments graded as sufficient are required.

		• A missing experiment can usually be repeated within the lab period. • Participation in a preliminary lab meeting and registration in the StudOn group for the course is required for participation in the experiments. • The preliminary meeting can be substituted by a learning module on StudOn, which then has to be worked on asynchronously during the lecture period.
11	Grading procedure	Practical achievement (pass/fail) ungraded (passed/not passed)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• lecture notes for the course • general literature on higher mathematics

1	Module name 92321	Electric Drives Electric drives	5 ECTS
2	Courses / lectures	Vorlesung: Electric Drives (2 SWS) Übung: Electric Drives (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Ingo Hahn Dr.-Ing. Jens Igney	

4	Module coordinator	Prof. Dr.-Ing. Ingo Hahn Dr.-Ing. Jens Igney
5	Contents	1. Introduction and overview 2. Applications 3. Systems structure 4. Physical foundations of electrical drives and machines 4.1 Energy conversion 4.2 Material properties 4.3 Loss mechanisms 4.4 Maxwell's equations 4.5 Electrical aspects 4.6 Magnetic aspects 4.7 Mechanical aspects 4.8 Thermal aspects 5. Mechanical components 5.1 Gearboxes 5.2 Clutches 5.3 Shafts 5.4 Flange 5.5 Encoders 5.6 Connectors 5.7 Rotor core 5.8 Stator core 6. Electrical machines 6.1 Brushed DC machines 6.2 Induction machine 6.3 Electrically excited SM 6.4 PM synchronous machine 6.5 Reluctance machines 7. Power electronics inverters 7.1 Power electronics devices 7.2 Uncontrolled rectifier 7.3 Controlled rectifier 7.4 DC-DC-converter 7.5 2-Level inverter

		7.6 3-Level inverter 7.7 Modulation technique 8. Introduction to drive control 8.1 Foundations of control 8.2 Controller design 8.3 Brushed DC machine 8.4 Cascaded control
6	Learning objectives and skills	On successful completion of this module, students will be able to: • recognise the basics and theoretical foundations of electric drives, the different technical system's components involved and their applications • understand the main operating principles of the different components of a drive system and explain and present them on request • distinguish between the different types of electric machines, power electronic rectifiers and inverters, explain their different characteristics and operating principles and demonstrate how to apply these components • recognise the general ideas and principles in control of electrical drives
7	Prerequisites	None
8	Integration in curriculum	semester: 3
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Conduct with questions in the answer-choice procedure
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 92323	Signal Theory	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Signaltheorie	5 ECTS
3	Lecturers	PD Dr.-Ing. Jürgen Seiler	

4	Module coordinator	PD Dr.-Ing. Jürgen Seiler
5	Contents	This lecture covers an introduction to the theory of continuous signals and continuous linear time-invariant (LTI) systems. At the beginning, elementary signals, the delta impulse, the convolution, and the correlation of signals are discussed. Subsequent to this, the frequency domain representation of signals by means of Fourier and Laplace transform is introduced, including the theorems and correspondences of these transforms. Next, the time-domain description of LTI systems by impulse response and convolution, differential equations, and state-space representation is presented. In addition to this, the description of systems in the frequency domain using eigen functions, the transfer function, the system function, and state-space representation is given. Furthermore, LTI systems with initial conditions are considered. Following, after linear phase, minimum phase, idealized, and all-pass system have been introduced, causality, the Hilbert transform, stability and feedback systems are discussed. The lecture closes with an overview of sampling systems and the sampling theorem for lowpass and bandpass signals.
6	Learning objectives and skills	The students • analyze continuous signals using the Fourier and Laplace transform • determine the impulse response, direct forms and state-space representation for continuous linear time-invariant (LTI) systems • calculate system and transfer functions for continuous LTI systems • analyze the properties of continuous LTI systems based on their time and frequency domain representation • classify continuous LTI systems based on the properties of distortionless, linear phase and minimum phase • evaluate the causality and stability of continuous LTI systems • assess the effects and limits of sampling continuous signals.
7	Prerequisites	For this lecture, a basic knowledge of electric circuits with resistance, capacitance and inductance is presupposed. Furthermore, knowledge of complex-valued pointers and transfer behavior of simple linear networks is required. This can be gained for example from the two modules "Fundamentals of Electrical Engineering I" and "Fundamentals of Electrical Engineering II" or by a combination of the modules "Introduction to Information and Communication Technologies" and "Electronics and Circuit Design". Students which did not attend these lectures (e.g. from study course Computational Engineering) can

		obtain the required prerequisites as well by private studies with the help of chapter 2 about physical fundamentals of electric circuits and chapter 3 about passive networks from the book "Elektronik und Schaltungstechnik" written by Oehme, Huemer, Pfaff and published by Hanser Verlag, München 2007.
8	Integration in curriculum	semester: 3
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 92347	Mechatronic components and systems (MCS)	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Philipp Beckerle
5	Contents	System thinking and integration - Interactions of hardware and software - Engineering design methods Mechanical components - Energy conductors and transformers - Control elements and energy storages Actuators - Electrodynamical and electromagnetic actuators - Fluid actuators and unconventional actuators • Sensors for measuring mechanical quantities • Control and information processing
6	Learning objectives and skills	On successful completion of this module, students will be able to: • Holistically understand mechatronic systems and optimize them using methods of system integration, control, and information processing. • Grundlegende mechanische Komponenten unterscheiden, charakterisieren, modellieren und im Rahmen des Systementwurfs auswählen und dimensionieren. • Distinguish, characterize, model, and select basic mechanical components to dimension them in terms of system design. • Describe electrodynamic, electromagnetic, fluid power, and unconventional actuators phenomenologically and mathematically to dimension them considering the overall system. • Describe sensors for measuring mechanical quantities phenomenologically and mathematically and dimension them taking into account the overall system.
7	Prerequisites	None
8	Integration in curriculum	semester: 4
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester

15	Teaching and examination language	english
16	Bibliography	• Rinderknecht, S. (2018). Einführung in die Mechatronik für den Maschinenbau. Shaker. • Isermann, R. (2007). Mechatronische Systeme: Grundlagen. Springer. • Janocha, H. (Ed.). (2013). Aktoren: Grundlagen und Anwendungen. Springer

1	Module name 92322	Sensors	5 ECTS
2	Courses / lectures	Vorlesung: Sensorik (2 SWS) Tutorium: Tutorium zu Sensorik (0 SWS) Übung: Sensors Exercise	5 ECTS - -
3	Lecturers	Prof. Dr.-Ing. Philipp Beckerle Niklas Bunte Matthias Voß Rodrigo Jose Velasco Guillen	

4	Module coordinator	Prof. Dr.-Ing. Philipp Beckerle
5	Contents	Introduction to sensor technology Transducer principles Sensor parameters Measurement of mechanical quantities Signal processing
6	Learning objectives and skills	Students will learn fundamental methods in measuring non-electrical quantities using electrical sensors and understand how these are applied to tasks from the field of modern industrial process measurement technology. To this end, the most important principles used in sensor technology to convert physical quantities into electrical signals will be covered. Moreover, application-oriented aspects of sensors for measuring electromechanical quantities in mechatronic components and systems will be addressed. This also includes the consideration of electrical circuits and algorithms for the evaluation of single or multiple transducers.
7	Prerequisites	None
8	Integration in curriculum	semester: 5
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	
16	Bibliography	- Tränkler, Hans-Rolf: "Sensortechnik - Handbuch für Praxis und Wissenschaft", 2. Aufl. 2014, Springer Vieweg - Hering, Eckert: "Sensoren in Wissenschaft und Technik - Funktionsweise und Einsatzgebiete", 2. Aufl. 2018, Springer Fachmedien Wiesbaden - Mitchell, H. B.: "Data fusion: concepts and ideas", 2012, Springer

1	Module name 92324	Stochastic Processes Stochastic processes	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr.-Ing. Heinrich Löllmann	
5	Contents	Probability and random variables Probability, random variables, univariate and multivariate probability distributions and densities; functions of random variables and their distributions and densities; expected values; special distributions (discrete and continuous); limit theorems Stochastic processes Distributions, densities and expected values of one-dimensional stochastic processes; stationarity, cyclostationarity, ergodicity; weakly stationary, continuous-time and discrete-time processes in the time and frequency domain; linear time-invariant (LZI) systems and weakly stationary processes Estimation theory Point and interval estimation; estimation criteria; prediction; classical and Bayesian parameter estimation (incl. MMSE, maximum likelihood, maximum a posteriori); Cramer-Rao bound; hypothesis testing and decision procedures (binary decisions, test statistics, chi-square test); binary decisions, Neyman-Pearson criterion Linear optimal filtering Orthogonality principle; continuous-time and discrete-time Wiener filtering; adaptive filters (LMS, NLMS); continuous-time and discrete-time signal matched filters	
6	Learning objectives and skills	The students - analyze the statistical properties of random variables and stochastic processes using probability densities and expected values - understand the differences between general, stationary and ergodic processes - know the special role of the Gaussian distribution and its effects on the properties of random variables and processes	

		- analyze the statistical properties of random processes at the output of LZI systems in the time domain and in the frequency domain - understand the differences of classical and Bayesian estimation, design and analyze MMSE and ML estimators for special estimation problems - know elementary hypothesis tests and decision procedures - analyze optimal filter problems and apply the orthogonality principle to derive optimal filters - understand and apply the concept of signal-adaptive filtering
7	Prerequisites	None
8	Integration in curriculum	semester: 4
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	- Rinderknecht, S. (2018). Einführung in die Mechatronik für den Maschinenbau. Shaker. - Isermann, R. (2007). Mechatronische Systeme: Grundlagen. Springer. - Janocha, H. (Ed.). (2013). Aktoren: Grundlagen und Anwendungen. Springer

1	Module name 92325	Digital Signal Processing Digital signal processing	5 ECTS
2	Courses / lectures	Vorlesung: Digitale Signalverarbeitung (3 SWS) Übung: Übung zu Digitale Signalverarbeitung (1 SWS)	5 ECTS -
3	Lecturers	Dr.-Ing. Heinrich Löllmann	

4	Module coordinator	Dr.-Ing. Heinrich Löllmann
5	Contents	• A/D and D/A conversion • ◦ Time-domain and z-domain representations ◦ Signal flow graphs ◦ Analytic computation of the frequency response ◦ Special systems (allpass, minimum phase, and linear phase systems) • Design of recursive and non-recursive filters • Multirate systems and filter banks • Frequency-domain signal analysis • Effects of finite wordlength
6	Learning objectives and skills	The students • analyze discrete-time linear time-invariant systems by determining the describing function and parameters • apply fundamental approaches for the design of discrete-time systems and evaluate their performance • understand the differences between various methods for spectral analysis and apply them to the analysis of given signals • understand methods to represent multirate systems and apply them for the representation of filter banks • know basic methods for the analysis of finite word length effects and apply them to discrete-time linear time-invariant systems.
7	Prerequisites	The course assumes knowledge of the basic theory of discrete-time deterministic signals as taught in lectures such as Signals and Systems II.
8	Integration in curriculum	semester: 5
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Written exam of 90 min duration. The following resources are allowed for this exam: a handwritten formulary totalling a two-sided DIN A4 sheet of paper and a non-programmable calculator. Answers can be given either in English or German
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h

		Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• A.V. Oppenheim and R. W. Schaffer: Discrete-Time Signal Processing, Prentice Hall, Third Edition, 1996 • J.G. Proakis and D.G. Manolakis: Digital Signal Processing, Prentice Hall, Second Edition, 1999

1	Module name 92326	Introduction to Communication Systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr.-Ing. Clemens Stierstorfer	
5	Contents	• Introduction • Source Signals • Transmission Channels • Analog Modulation Techniques • Pulse Code Modulation • Basic Concepts of Information Theory • Digital Transmission Concepts	
6	Learning objectives and skills	• The students describe the tasks of communication systems. They describe and model signals mathematically with random processes and can transform these into the frequency domain. They convert linear quantities into logarithmic representations (and back) and use level quantities correctly. • Students analyze analog source signals, know and use the characteristics and assumptions regarding band limiting, peak limiting, etc. They distinguish between analog and digital source signals and describe the latter using the commonly used parameters. • The students explain the definition of the transmission channel as well as possible causes for signal distortions and other interference influences. They describe the channel in equivalent complex baseband, in particular they describe and analyze the propagation of signals in radio transmission as well as on cables with the effects occurring there (e.g. multipath propagation, attenuation, etc.). They use additive white noise to model physical noise processes in time and frequency domains. Likewise, they use and analyze the AWGN channel and frequency selective fading channel models. They evaluate transmission methods based on power efficiency and bandwidth efficiency criteria. • The students analyze and describe mathematically the common amplitude modulation methods (single and double sideband modulation, quadrature amplitude modulation) in time and frequency domain. This also applies to frequency modulation methods. They evaluate these modulation methods in the power-bandwidth diagram and analyze the influence of additive interferers. They describe the basic structures of the associated receivers. • Students mathematically describe the transition from analog to digital signals and analyze the effects of sampling and quantization. They examine the effects of companding in	

		quantization and the requirements for differential pulse code modulation. - Students use Shannon's information measure, the source coding theorem, and mutual information to mathematically describe message transmission over perturbed channels. They explain the channel coding theorem and analyze in detail the AWGN channel and its variants with respect to information theoretic quantities. - The students explain digital pulse amplitude modulation and analyze the associated transmitters, the signals and the coherent demodulation in time and frequency domain. They determine the error probability and use the Gaussian error integral and the error function for this purpose. They evaluate digital transmission methods in the power-bandwidth diagram. Students understand the motivation for using channel coding in digital transmission.
7	Prerequisites	None
8	Integration in curriculum	semester: 4
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Homework Homework assignments will be made available on StudOn on a regular basis to support the learning process.
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	- Lecture notes will be provided - Kammeyer, K.D.: Nachrichtenübertragung. Teubner, Stuttgart, 2.Aufl., 1996 (in German). - Haykin, S.; Moher, M.: Communication Systems. John Wiley & Sons, Inc., New York, 2009.

1	Module name 47603	Dynamical Systems and Control	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Knut Graichen Dr.-Ing. Andreas Völz
5	Contents	This course introduces the fundamentals of dynamical systems and control design with a focus on linear single-input single-output system. The course covers the following topics: • Dynamical systems: state space formulation, physical examples, linearization • Frequency domain: Laplace transform, analysis and control based on transfer functions • Time domain: analysis, control and observer design based on state space models
6	Learning objectives and skills	The students will be able to • describe dynamical systems by differential equations • compute a linearized model for nonlinear systems • describe and analyze dynamical systems in the Laplace domain • design basic controllers in the Laplace domain • describe and analyze dynamical systems in the state space • design basic controllers and observers in the state space
7	Prerequisites	• Basic knowledge of advanced mathematics
8	Integration in curriculum	semester: 4
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable (90 minutes)
11	Grading procedure	Variable (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• K.J. Aström and R.M. Murray: Feedback systems - An Introduction for Scientists and Engineers, Princeton University Press, 2008.

		• E. Hendricks, O. Jannerup, and P.H. Sørensen: Linear systems control: deterministic and stochastic methods, Springer, 2008. • L. Padulo and M.A. Arbib: System Theory, W.B. Saunders Company, 1974. • G.C. Goodwin, S.F. Graebe and M.E. Salgado: Control System Design, Prentice Hall, 2001. • W.J. Rugh: Linear System Theory, Prentice Hall, 1996. • C.T. Chen: Control System Design, Pond Woods Press, 1987. • T. Kailath: Linear Systems, Prentice Hall, 1980.

1	Module name 92241	Modeling of Control Systems	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Modeling of Control Systems (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Thomas Moor	

4	Module coordinator	Prof. Dr. Thomas Moor
5	Contents	• Ordinary differential equations as models of engineering processes • State space representation and linearisation • Control engineering models of mechanical systems • Control engineering models of chemical processes • Numerical methods for the solution of ordinary differential equations
6	Learning objectives and skills	The students • explain how to derive models for engineering processes • develop models for the control of basic technical processes • develop models for complex mechanical systems • explain established models for basic chemical processes • discuss and evaluate methods for the numerical solution of ordinary differential equations
7	Prerequisites	None
8	Integration in curriculum	semester: 5
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Woods, R.L., Lawrence, K.L.: Modeling and Simulation of Dynamic Systems, Prentice Hall, 1997

1	Module name 94967	Machine Learning for Control Systems	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Machine Learning for Control Systems (4 SWS)	5 ECTS
3	Lecturers	Dr.-Ing. Andreas Michalka	

4	Module coordinator	Prof. Dr.-Ing. Knut Graichen Dr.-Ing. Andreas Michalka
5	Contents	The lecture teaches the basic concepts of machine learning methods, which are currently increasingly being used in control engineering. The applications range from simple parameter identification tasks to control methods based entirely on machine learning. Lecture contents: • Basic Concepts of Machine Learning and Stochastic Processes • Iterative Learning Control • Linear Regression • Gaussian Process Regression • Logistic Regression and Support Vector Machine • Artificial Neural Networks • Reinforcement Learning
6	Learning objectives and skills	After successful completion of the module, students will be able to: • explain the basic concepts of machine learning and the optimization methods used for it as well as the application of such methods in control engineering. • distinguish between and explain in detail the functional principles of different machine learning methods. • apply various methods of machine learning to the design of control systems.
7	Prerequisites	Recommended prior knowledge: Basics of advanced mathematics and control theory
8	Integration in curriculum	semester: 5
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 44411	Embedded Systems	5 ECTS
2	Courses / lectures	Übung: Übung zu Eingebettete Systeme (2 SWS) Vorlesung: Eingebettete Systeme (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Batuhan Sesli Khalil Esper Dominik Walter PD Dr.-Ing. Frank Hannig Prof. Dr.-Ing. Jürgen Teich	

4	Module coordinator	Prof. Dr.-Ing. Jürgen Teich
5	Contents	Schwerpunkt des Moduls ist der Entwurf und die Implementierung eingebetteter Systeme unter Einsatz formaler Methoden und rechnergestützter Entwurfsverfahren. Unter eingebetteten Systemen versteht man Rechensysteme, die auf einen Anwendungsbereich zugeschnitten (z.B. mobile Kommunikationsgeräte, Chipkartensysteme, Industriesteuerungen, Unterhaltungselektronik, Medizintechnik) und in einen technischen Kontext eingebunden sind. Das große Interesse am systematischen Entwurf von heterogenen eingebetteten Systemen ist verursacht durch die steigende Vielfalt und Komplexität von Anwendungen für eingebettete Systeme, die Notwendigkeit, Entwurfs- und Testkosten zu senken sowie durch Fortschritte in Schlüsseltechnologien (Mikroelektronik, formale Methoden). <i>The focus of this module is the design and implementation of embedded systems using formal methods and computer-aided design techniques. Embedded systems are computing systems tailored for a particular application (e.g., mobile communication devices, smart card systems, industrial control, consumer electronics, medical technology) and integrated into a technical context. The keen interest in the systematic design of heterogeneous embedded systems is driven by the increasing diversity and complexity of embedded system applications, the need to reduce design and test costs, and advances in key technologies (microelectronics, formal methods).</i>
6	Learning objectives and skills	Fachkompetenz - Wissen - Die Studierenden setzen sich mit einem aktuellen Forschungsgebiet auseinander. The students deal with a current field of research. Fachkompetenz - Verstehen - Die Studierenden verstehen grundlegende Konzepte des Entwurfs eingebetteter Systeme. The students become familiar with the fundamental concepts of designing of embedded systems. Fachkompetenz - Anwenden - Die Studierenden wenden grundlegende Algorithmen an zur Analyse und Optimierung von Hardware-Architekturen und Echtzeit-Softwaresystemen. The students apply basic

		algorithms to analyze and optimize hardware architectures and real-time software systems. Die Studierenden erfassen den Hardware/Software-Entwurf von Systemen mit harten Beschränkungen. The students understand the hardware/software design of hard-constrained systems.
7	Prerequisites	Die Auswahl dieses Moduls schließt die Auswahl der Module „Eingebettete Systeme (Vorlesung mit erweiterten Übungen)“ und „Eingebettete Systeme (Vorlesung mit Übungen)“ aus. <i>Selecting this module excludes the selection of the modules “Embedded Systems (Lecture with Extended Exercises)” and “Embedded Systems (Lecture with Exercises)”.</i> Organisatorisches: - Die Vorlesung erfolgt in deutscher Sprache. Zusätzlich stehen Folien und Vorlesungsaufzeichnungen in englischer Sprache zur Verfügung. - Die Übungen werden sowohl auf Deutsch als auch auf Englisch angeboten. - Studierende können die Prüfung wahlweise auf Deutsch oder Englisch ablegen. Organizational: - The lecture is given in German. Slides and lecture recordings are also provided in English. - German as well as English exercises are offered. - Students can choose between taking the exam either in German or English.
8	Integration in curriculum	semester: 3
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german english
16	Bibliography	Empfohlenes Buch zur Begleitung und Vertiefung: Teich J., Haubelt C.: "Digitale Hardware/Software-Systeme: Synthese und Optimierung", Springer-Verlag, 2007, ISBN: 978-3-540-46822-6 Weitere Informationen:

	https://www.cs12.tf.fau.de/lehre/lehrvorlesungen/eingebettete-systeme/

1	Module name 92329	Numerics for Engineers I Numerics for engineers I	5 ECTS
2	Courses / lectures	Vorlesung: Numerics for Engineers I (2 SWS) Praktikum: Übungen Numerics for Engineers I (2 SWS)	- -
3	Lecturers	PD Dr. Nicolas Neuß	

4	Module coordinator	Dr. Michael Fried
5	Contents	Basic Numerics • direct and iterative solver for systems of linear equations • interpolation by polynomials and by splines • numerical quadrature: Newton-Cotes formulas, Gaussian Quadrature Numerics for Ordinary Differential Equations • explicit and implicit Euler's Method, stability, convergence • Runge-Kutta Methods • Adams-Moulton and Adams-Bashforth Methods
6	Learning objectives and skills	On successful completion of this module, students will: • know different numerical methods for systems of linear equations • be able to evaluate different numerical methods • know numerical methods for interpolation • know and be able to evaluate basic quadrature rules • know and be able to evaluate basic discretisation techniques for ODEs • know and be able to implement numerical algorithms for above listed methods
7	Prerequisites	None
8	Integration in curriculum	semester: 5
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (60 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• Van Loan: Introduction to Scientific Computing, Matlab Curriculum Series • notes provided by the teaching person

1	Module name 92331	Simulation of Autonomous Systems Simulation of autonomous systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Franziska Mathis-Ullrich Dr. Marlene Reuschel
5	Contents	The simulation of autonomous systems includes understanding of dynamic systems theory and dynamic simulation. A dynamic system is defined as a system that changes its states over time. Simulation of dynamic systems involves using computer programs to model systems interacting with other systems and/or their environments. This course will provide an overview of different types of dynamic systems (for example linear vs. non-linear, continuous vs. discrete, and others). This is followed by introducing methods to analyze these systems as well as providing the basics of dynamic system simulation using simulation tools, such as MATLAB/Simulink.
6	Learning objectives and skills	• Students have a good overview of types of dynamic systems. • Students understand the specific requirements to solving dynamic systems. • Students understand the basics of dynamic system simulation and can simulate their own dynamic system with the tool.
7	Prerequisites	Students are recommended to familiarize themselves with programming in and syntax of MATLAB and modelling with MATLAB/Simulink.
8	Integration in curriculum	semester: 4
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• Rinderknecht, S. (2018). Einführung in die Mechatronik für den Maschinenbau. Shaker. • Isermann, R. (2007). Mechatronische Systeme: Grundlagen. Springer. • Janocha, H. (Ed.). (2013). Aktoren: Grundlagen und Anwendungen. Springer

1	Module name 92314	Automation Laboratory Laboratory course: Electrical engineering and automation	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Knut Graichen
5	Contents	This lab course consists of two experiments for control engineering, sensorics, and electrical drives: • State feedback control of a reduced helicopter model (LRT) • Control of a three-tank system (LRT) • Distance and displacement sensors (ASM) • Calibration of a sensor glove (ASM) • Automatic filling machine (EAM) • Positioning system "Hot wire" (EAM)
6	Learning objectives and skills	The students • apply the methodological knowledge from the automation related core modules on control engineering, sensorics, and electrical drives to different experiments • interpret the observations and evaluate the results with regard to the employed methods and devices • acquire practical experience in the use of automation methods and tools in control engineering, sensorics, and electrical drives
7	Prerequisites	Basic knowledge of the modules • Dynamical Systems and Control • Sensors • Electric Drives
8	Integration in curriculum	semester: 6
9	Module compatibility	Pflichtmodul Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 45 h Independent study: 30 h
14	Module duration	1 semester
15	Teaching and examination language	
16	Bibliography	

Human-system interfaces - Core modules

1	Module name 92345	Human-centered mechatronics and robotics	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Philipp Beckerle	
5	Contents	- Human-oriented design methods - Biomechanics Motions, measurement, and analysis Biomechanical models - Elastic actuators - Control methods Cognitive and physical human-robot interaction Empirical research methods - Research process and experiment design - Research methods, interferences, and ethics System integration and fault treatment The exercise will combine simulation sessions and a flip-the-classroom seminar where student groups present recent research papers and discuss them with all attendees.	
6	Learning objectives and skills	On successful completion of this module, students will be able to: - Tackle the interdisciplinary challenges of human-centered robot design. - Use engineering methods for modeling, design, and control to develop human-centered robots. - Apply methods from psychology (perception, experience), biomechanics (motion and human models), and engineering (design methodology) and interpret their results. - Develop robotic systems that are provide user-oriented interaction characteristics in addition to efficient and reliable operation.	
7	Prerequisites	None	
8	Integration in curriculum	semester: 6	
9	Module compatibility	Human-system Interfaces - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242	
10	Method of examination	Written examination (90 minutes)	
11	Grading procedure	Written examination (100%)	
12	Module frequency	Only in summer semester	
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h	

14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• Ott, C. (2008). Cartesian impedance control of redundant and flexible-joint robots. Springer. • Whittle, M. W. (2014). Gait analysis: an introduction. Butterworth-Heinemann. • Burdet, E., Franklin, D. W., & Milner, T. E. (2013). Human robotics: neuromechanics and motor control. MIT press. • Gravetter, F. J., & Forzano, L. A. B. (2018). Research methods for the behavioral sciences. Cengage Learning. • Further topic-specific text books and selected research articles.

1	Module name 92359	Robot mechanisms and user interfaces	5 ECTS
2	Courses / lectures	Vorlesung: Robot mechanisms and user interfaces (2 SWS) Übung: Robot mechanisms and user interfaces (Exercise) (2 SWS) Attendance is not mandatory.	5 ECTS 5 ECTS
3	Lecturers	Rodrigo Jose Velasco Guillen Prof. Dr.-Ing. Philipp Beckerle	

4	Module coordinator	Prof. Dr.-Ing. Philipp Beckerle Mehmet Ege Cansev
5	Contents	Mechanical components, short overview/repetition of machine elements, Robot mechanisms, Kinematic parameters and calculations, Evaluation metrics and design methods, Redundant mechanisms and actuation, Human-robot interfaces, Intend detection (sensing) and haptic stimulation (actuators), Interface system design and evaluation, Mechanical and cognitive user models A flip-the-classroom seminar with student presentations and discussion is part of the lecture. The laboratory exercise will be a mini design project in which student groups create their own low-budget haptic human-machine interfaces.
6	Learning objectives and skills	On successful completion of this module, students will be able to: Understand robot mechanisms and apply kinematic calculations for their design and control, Exploit redundancy in kinematic chains and actuation systems, Know components of human-machine interfaces and be able to design such systematically, Know approaches to model human characteristics and behavior for human-machine interface design.
7	Prerequisites	None
8	Integration in curriculum	semester: 5;6
9	Module compatibility	Human-system Interfaces - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Attendance accounts to 56h and self-study to 94h. It is a written exam that accounts to 100% of the final grade.
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester

15	Teaching and examination language	english
16	Bibliography	Rinderknecht, S. (2018). Einführung in die Mechatronik für den Maschinenbau. Shaker. Lenarcic, J., Bajd, T., & Stanisic, M. M. (2013). Robot mechanisms. Springer. Hatzfeld, C., & Kern, T. A. (2016). Engineering haptic devices. Springer. Selected research articles.

1	Module name 645618	Human Computer Interaction Human computer interaction	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Björn Eskofier Madeleine Flaucher
5	Contents	Das Modul vermittelt Konzepte, Prinzipien, Modelle, Methoden und Techniken für die effektive Entwicklung von benutzerfreundlichen Mensch-Computer-Schnittstellen. Das Thema moderner Benutzungsschnittstellen wird dabei für klassische Computer aber auch für mobile Geräte, eingebettete Systeme, Automobile und intelligente Umgebungen betrachtet. Die folgenden Themen werden im Modul behandelt: • Einführung in die Grundlagen der Mensch-Computer-Interaktion, historische Entwicklung • Entwurfsprinzipien und Modelle für moderne Benutzungsschnittstellen und interaktive Systeme • Informationsverarbeitung des Menschen, Wahrnehmung, Motorik, Eigenschaften und Fähigkeiten des Benutzers • Interaktionskonzepte und -stile, Metaphern, Normen, Regeln und Style Guides • Ein- und Ausgabegeräte, Entwurfsraum für interaktive Systeme • Analyse-, Entwurfs- und Entwicklungsmethoden und -werkzeuge für Benutzungsschnittstellen • Prototypische Realisierung und Implementierung von interaktiven Systemen, Werkzeuge • Architekturen für interaktive Systeme, User Interface Toolkits und Komponenten • Akzeptanz, Evaluationsmethoden und Qualitätssicherung Contents: The module aims to teach basic knowledge of concepts, principles, models, methods and techniques for developing highly user-friendly Human-Computer Interfaces. Beyond traditional computer systems, modern user interfaces are also discussed in the context of automobile and intelligent environments, mobile devices and embedded systems. This module addresses the following topics: • Introduction to the basics of Human-Computer Interaction • Design principles and models for modern user interfaces and interactive systems • Information processing of humans, perception, motor skills, properties and skills of the users • Interaction concepts, metaphors, standards, norms and style guides

		• In- and output devices, design space for interactive systems • Analysis-, design- and development of methodologies and tools for easy-to-use user interfaces • Prototypic implementation of interactive systems • Architectures for interactive systems, User Interface Toolkits and components • Acceptance, evaluation methods and quality assurance
6	Learning objectives and skills	• Studierende entwickeln ein Verständnis für Modelle, Methoden und Konzepte der Mensch-Computer-Interaktion. • Sie lernen verschiedene Ansätze für den Entwurf, die Entwicklung und Bewertung von Benutzungsschnittstellen kennen und verstehen deren Vor- und Nachteile. • Die Teilnahme an der Veranstaltung versetzt Studierende in die Lage, einen Entwicklungsprozess in der Mensch-Computer-Interaktion zu verstehen und umzusetzen. • Sie werden weiterhin in die Lage versetzt, dies vor dem Hintergrund der Informationsverarbeitungsfähigkeit, Wahrnehmung und Motorik des Benutzers zu gestalten. • Passende Methoden der Evaluation sowie Akzeptanz- und Qualitätssicherung werden erlernt. Learning Objectives and Competences: • Students develop an understanding of models, methods and concepts in the field of Human-Computer Interaction. • They learn different approaches for designing, developing and evaluating User Interfaces and their advantages and disadvantages. • Joining the course enables students to understand and execute a development process in Human-Computer Interaction. • Students will be able to do a UI evaluation by learning the basics of information processing, perception and motoric skills of the user. • Appropriate evaluation methods, as well as acceptance and quality assurance aspects, will be learned.
7	Prerequisites	None
8	Integration in curriculum	semester: 5;6
9	Module compatibility	Human-system Interfaces - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Electronic examination Electronic exam (in presence), 90min
11	Grading procedure	Electronic examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h

14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 47616	Intent Detection and Feedback Intent detection and feedback	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Claudio Castellini
5	Contents	• Introduction to the problems of intent detection and somatosensory feedback: motivation, taxonomy, historical background. • Intent detection: theory and philosophical issues; defining the problem and the ground truth; success metrics; signals for intent detection; sensors for intent detection; feature extraction; applications of machine learning to the problem. • Somatosensory feedback: theory and physiology; sensory substitution; embodiment and agency induced by it; modalities of actuation; practical issues and metrics of performance. • Intent detection and somatosensory feedback in prosthetics: usefulness, success and challenges. • Intent detection and somatosensory feedback in rehabilitation and exoskeletons: usefulness, success and challenges. • Intent detection and somatosensory feedback in gaming and non-reha fields.
6	Learning objectives and skills	Students who have followed the module • have a broad understanding of intent detection and somatosensory feedback, especially in the frame of Rehabilitation and Assistive Robotics • can conceive and design a research project in the related subfield of the subject • have knowledge about the clinical and industrial situation of intent detection and feedback, especially including the problems and challenges of each technique and method • can tackle previously unknown problems
7	Prerequisites	Recommended: basic maths, especially statistics; fundamentals of signal processing and machine learning; mid-level programming Python, C# or similar; fundamentals of experimental psychology
8	Integration in curriculum	semester: 5;6
9	Module compatibility	Human-system Interfaces - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable (60 minutes) Written examination (60 min)
11	Grading procedure	Variable (100%) Written examination (100 %)

12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• [2010] Control of Hand Prostheses Using Peripheral Information, S. Micera, J. Carpaneto and S. Raspopović. • [2012] Control of Upper Limb Prostheses: Terminology and Proportional Myoelectric ControlA Review, A. Fougner, Ø. Stavdahl, P. J. Kyberd, Y. G. Losier and P. A. Parker. • [2015] Michael R Tucker et al., Control strategies for active lower extremity prosthetics and orthotics: a review, JNER 12:1 • [2015] A survey of sensor fusion methods in wearable robotics, D. Novak and R. Riener • [2016] Incremental Learning of Muscle Synergies: From Calibration to Interaction, C. Castellini. • [2018] JA Spanias, AM Simon, SB Finucane, EJ Perreault and LJ Hargrove, Online adaptive neural control of a robotic lower limb prosthesis, J Neural Eng. 15(1) • [2020] Jacob Rosen and Peter Walker Ferguson (eds.), Wearable Robotics Systems and Applications, Academic Press Elsevier • [2021] Michele Xiloyannis, Ryan Alicea, Anna-Maria Georgarakis, Florian L. Haufe, Peter Wolf, Lorenzo Masia and Robert Riener, Soft robotic suits: State of the art, core technologies and open challenges, IEEE Transactions on Robotics

Human-system Interfaces - Specialization modules

1	Module name 96310	Image and Video Compression Image and video compression	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Andre Kaup
5	Contents	Multi-Dimensional Sampling - Sampling theorem revisited, 2D sampling, spatiotemporal sampling, motion in 3D sampling Entropy and Lossless Coding - Entropy and information, variable length codes, Huffman coding, unary coding, Golomb coding, arithmetic coding Statistical Dependency - Joint entropy and statistical dependency, run-length coding, fax compression standards Quantization - Rate distortion theory, scalar quantization, Lloyd-Max quantization, entropy coded scalar quantization, embedded quantization, adaptive quantization, vector quantization Predictive Coding - Lossless predictive coding, optimum 2D linear prediction, JPEG-LS lossless compression standard, differential pulse code modulation (DPCM) Transform Coding - Principle of transform coding, orthonormal transforms, Karhunen-Loève transform, discrete cosine transform, bit allocation, compression artifacts Subband Coding - Principle of subband coding, perfect reconstruction property, discrete wavelet transform, bit allocation for subband coding Visual Perception and Color - Anatomy of the human eye, sensitivity of the human eye, color spaces, color sampling formats Image Coding Standards - JPEG and JPEG2000 Interframe Coding - Interframe prediction, motion compensated prediction, motion estimation, motion compensated hybrid coding Video Coding Standards - H.261, H.263, MPEG-1, MPEG-2 / H.262, H.264 / MPEG-4 AVC, H.265 / MPEG-H HEVC
6	Learning objectives and skills	The students - visualize multi-dimensional sampling and the influence of motion within the video signal - differentiate and evaluate different methods for lossless image and video coding

		• understand and analyze mutual entropy and statistical dependencies in image and video data • determine scalar and vector quantization for different optimization criteria (minimum mean square error, entropy coding, embedded quantization) • determine and evaluate optimal one-dimensional and two-dimensional linear predictor • apply prediction and quantization for a common DPCM system • understand the principle and effects of transform and subband coding for image data including optimal bit allocation • describe the principles of the human visual system for brightness and color • analyze block diagrams and the functioning of hybrid coders and decoders for video signals • know the prevailing international standards of ITU and MPEG for image and video compression.
7	Prerequisites	Lectures on Signal and Systems and Communication Systems strongly recommended
8	Integration in curriculum	semester: 2
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written or oral (90 minutes) Written exam of 90 min duration
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	J.-R. Ohm: Multimedia Communications Technology, Springer, 2004

1	Module name 92343	Image, Video, and Multidimensional Signal Processing Image, video, and multidimensional signal processing	5 ECTS
2	Courses / lectures	Vorlesung: Image, Video, and Multidimensional Signal Processing (2 SWS) Übung: Supplements Image, Video, and Multidimensional Signal Processing	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Andre Kaup Katja Kossira	

4	Module coordinator	Prof. Dr.-Ing. Andre Kaup
5	Contents	Punktoperationen Histogrammausgleich, Gamma-Korrektur Binäroperationen Morphologische Filter, Erosion, Dilatation, Opening, Closing Farbräume Trichromat, RGB- Farbraum, HSV-Farbraum Mehrdimensionale Signale und Systeme Theorie mehrdimensionaler Signale und Systeme, Impulsantwort, lineare Bildfilterung, Leistungsspektrum, Wiener Filter Interpolation von Bildsignalen Bilineare Interpolation, Bicubische Interpolation, Spline Interpolation Merkmalsdetektion in Bildern Bildmerkmale, Kantendetektion, Hough Transformation, Harris Ecken Detektor, Texturmerkmale, Grauwertematrix Skalierungsraumdarstellung LoG, DoG, SIFT, SURF Bildabgleich Projektive Abbildungen, Blockabgleich, Optischer Fluss, Merkmalsbasierter Abgleich mittels SIFT und SURF, RANSAC Bildsegmentierung Amplituden Schwellenwertermittlung, K-Means Clustering, Bayes Klassifikation, Regionen-basierte Segmentierung, kombinierte Segmentierung und Bewegungsschätzung, zeitliche Segmentierung von Videos Bildverarbeitung im Transformationsbereich Unitäre Transformation, Karhunen-Loeve Transformation, separable Transformationen, Haar und Hadamard Transformation, DFT, DCT Content: Point operations Histogram equalization, gamma correction

		Binary operations Morphological filters, erosion, dilation, opening, closing Color spaces Trichromacy, red-green-blue color spaces, color representation using hue, saturation and value of intensity Multidimensional signals and systems Theory of multidimensional signals and systems, impulse response, linear image filtering, power spectrum, Wiener filtering Interpolation of image signals Bi-linear interpolation, bi-cubic interpolation, spline interpolation Image feature detection Image features, edge detection, Hough transform, Harris corner detector, texture features, co-occurrence matrix Scale space representation Laplacian of Gaussian, difference of Gaussian, scale invariant feature transform, speeded-up robust feature transform Image matching Projective transforms, block matching, optical flow, feature-based matching using SIFT and SURF, random sample consensus algorithm Image segmentation Amplitude thresholding, k-means clustering, Bayes classification, region-based segmentation, combined segmentation and motion estimation, temporal segmentation of video Transform domain image processing Unitary transform, Karhunen-Loeve transform, separable transform, Haar and Hadamard transform, DFT, DCT
6	Learning objectives and skills	The students • understand point operations for image data and gamma correction • test the effects of rank order and median filters for image data • evaluate and differentiate between different color spaces for image data • explain the principle of two-dimensional linear filtering for image signals • calculate and evaluate the two-dimensional discrete Fourier transform of an image signal • determine enlarged discrete image signals by bi-linear and spline interpolation • verify image data for selected texture, edge and motion features • analyze image and video data for features in different scale spaces • explain and evaluate methods for the matching of image data

		• segment image data by implementing basic classification and clustering methods • understand the principle of transformations on image data and apply them exemplarily
7	Prerequisites	None
8	Integration in curriculum	semester: 5
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• J.-R. Ohm: Multimedia Content Analysis, Springer, 2016 • J. W. Woods: Multidimensional Signal, Image, and Video Processing and Coding, Academic Press, 2nd edition, 2012

1	Module name 816185	Body Area Communications Body area communications	2,5 ECTS
2	Courses / lectures	Vorlesung: Body Area Communications (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Georg Fischer	

4	Module coordinator	Prof. Dr.-Ing. Georg Fischer
5	Contents	Contents: The Lecture and exercise deals with the following topics: • Introduction to Body Area Communications • Electromagnetic Characteristics of Human Body • Electromagnetic Analysis Methods • Body Area Channel Modeling • Modulation/Demodulation • Body Area Communication Performance • Electromagnetic Compatibility Consideration
6	Learning objectives and skills	Learning objectives • Students understand the challenges in designing Body Area Communication (BAC) systems • Students can conduct basic design decisions with BAC systems, like frequency and modulation selection • Students understand electromagnetic wave propagation in bodies • Students understand the frequency dependent loss and propagation behavior of electromagnetic waves • Students can analyze the communication performance of a BAC system • Students can evaluate Electromagnetic Compatibility of a BAC system • Students can assess the field strength inside body and relate it to regulatory limits like SAR (Specific Absorption rate), frequency dependent maximum electrical and magnetic field strength • Students can sketch block diagrams of BAC systems • Students can derive channel models for BAC
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h

14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 47623	Human-Robot Co-Adaptation Human-robot co-adaptation	5 ECTS
2	Courses / lectures	Vorlesung: Human-Robot Co-Adaptation, Theory - - THIS COURSE IS ONLY ONLINE in WS25! Please follow the links on Studon. (2 SWS) Übung: Human-Robot Co-Adaptation, Exercises - - THIS COURSE IS ONLY ONLINE in WS25! Please follow the links on Studon. (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Dr. rer. nat. Sabine Thürauf Prof. Dr. Claudio Castellini	

4	Module coordinator	Prof. Dr. Franziska Mathis-Ullrich
5	Contents	• Introduction to user studies: designing them; carrying them out; statistical tools to evaluate them • human-robot interaction, with specific focus upon rehabilitation and assistive robotics (prosthetics, exoskeletons, walking aids); • intent detection, somatosensory feedback and sensory substitution; • measurement of relevant changes in the user's behaviour and signals and in the robotic artefact; • co-adaptation and the related clinical perspective.
6	Learning objectives and skills	Students who have followed the course • have a broad understanding of the concept of co-adaptation • can conceive and design an intent-detection + feedback system which will potentially induce co-adaptation • can then analyse the data, both offline and online • can tackle previously unknown problems
7	Prerequisites	Recommended: • basic maths, especially statistics • fundamentals of signal processing and machine learning • mid-level programming (Python, C# or similar) • fundamentals of experimental psychology.
8	Integration in curriculum	semester: 1
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable (120 minutes) Written exam, 120 min.
11	Grading procedure	Variable (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester

15	Teaching and examination language	english
16	Bibliography	• [2015] A survey of sensor fusion methods in wearable robotics, D. Novak and R. Riener • [2016] Incremental Learning of Muscle Synergies: From Calibration to Interaction, C. Castellini. • [2016] New developments in prosthetic arm systems, I. Vujaklija, D. Farina and O.C. Aszmann. • [2017] Hahne, J. M., Markovic, M., & Farina, D. (2017). User adaptation in Myoelectric Man-Machine Interfaces. Scientific Reports, 7. • [2021] Farina, D., et al. (2021). Toward higher-performance bionic limbs for wider clinical use. Nature biomedical engineering.

1	Module name 47617	Rehabilitation and Assistive Robotics Rehabilitation and assistive robotics	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Claudio Castellini
5	Contents	• Introduction to Rehabilitation and Assistive Robotics: motivation, taxonomy, historical background • Prosthetics: upper- and lower limb prosthetics; clinical, mechatronics and societal challenges; machine learning and intent detection applied to prosthetics; signals and sensors. • Exoskeletons and exo-suits: realms of application, mechatronic and ergonomic challenges; intent detection and feedback; clinical acceptance, feasibility and effectiveness.
6	Learning objectives and skills	Students who have followed the module • have a broad understanding of Rehabilitation and Assistive Robotics, the motivations, problems and challenges • can conceive and design a research project in the related subfield of the subject • have knowledge about the clinical and industrial situation in RAR • can tackle previously unknown problems
7	Prerequisites	Recommended: basic maths, especially statistics; fundamentals of signal processing and machine learning; mid-level programming (Python, C# or similar); fundamentals of experimental psychology
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable (60 minutes) Written examination (60 min)
11	Grading procedure	Variable (100%) Written examination (100 %)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• [2002] Control of Multifunctional Prosthetic Hands by Processing the Electromyographic Signal, M. Zecca, S. Micera, M. C. Carrozza and P. Dario.

		• [2010] Control of Hand Prostheses Using Peripheral Information, S. Micera, J. Carpaneto and S. Raspopović. • [2012] Control of Upper Limb Prostheses: Terminology and Proportional Myoelectric ControlA Review, A. Fougner, Ø. Stavadahl, P. J. Kyberd, Y. G. Losier and P. A. Parker. • [2015] Michael R Tucker et al., Control strategies for active lower extremity prosthetics and orthotics: a review, JNER 12:1 • [2018] JA Spanias, AM Simon, SB Finucane, EJ Perreault and LJ Hargrove, Online adaptive neural control of a robotic lower limb prosthesis, J Neural Eng. 15(1) • [2020] Jacob Rosen and Peter Walker Ferguson (eds.), Wearable Robotics - Systems and Applications, Academic Press Elsevier • [2021] Michele Xiloyannis, Ryan Alicea, Anna-Maria Georgarakis, Florian L. Haufe, Peter Wolf, Lorenzo Masia and Robert Riener, Soft robotic suits: State of the art, core technologies and open challenges, IEEE Transactions on Robotics

1	Module name 93101	AI in medical robotics	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: AI in Medical Robotics (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Franziska Mathis-Ullrich Dr.-Ing. Christian-Peter Kunz	

4	Module coordinator	Prof. Dr. Franziska Mathis-Ullrich
5	Contents	This module is concerned with artificial intelligence technologies in medical robotics and with methods that establish different forms of intelligence in medical robotic systems. Participants will become familiar with the design and application of AI methods and algorithms for perception, motor control, planning, cognition and learning and with their application in biorobotic systems and robotic solutions for diagnosis and treatment. Application domains include minimally invasive surgery, motor rehabilitation, exoskeletons and assistive devices, as well as medical service robotics. The taught methods will be applied to application data during designated computer exercises that are integrated into the course. Topics include, but are not limited to: • Basic principles and classification of artificial intelligence • Overview of AI methods and technologies in medical imaging • Implications of surgical workflow planning using AI methods • Motion planning in robotic surgery, rehabilitation robots and medical service robots • Perception in robotic surgery, rehabilitation robots and assistive robots • Motion planning in robotic surgery, rehabilitation robots and assistive robots • Adaptation and Learning in Human-Robot Interaction • Design criteria and regulations for AI-based medical systems
6	Learning objectives and skills	• Students are able to employ artificial intelligence technologies and methods for applications in medical robotics. • They are capable of understanding and handling the complexity of biorobotic AI systems and have command of a versatile set of methods for analyzing and further advancing such systems. • They are able to combine different tools and methods to achieve intelligent perception, planning, control, learning and cognition in robotic solutions for minimally invasive surgery, motor rehabilitation robotics, and medical service robotics.
7	Prerequisites	Participants should be familiar with fundamentals of linear algebra. It is advantageous but not required to have some prior knowledge on robotics, basic methodologies of AI, and basic probability theory.
8	Integration in curriculum	semester: 1
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242

		Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination Written examination (60 min)
11	Grading procedure	Written examination (100%) Written examination (100 %)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 47708	Robotics in Surgery and Diagnostics Robotics in surgery and diagnostics	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Franziska Mathis-Ullrich
5	Contents	To provide motivation, the various scenarios of robot use in the surgical environment are explained and classified using examples. The fundamentals of robotics are addressed, including different kinematic forms, and key parameters such as degrees of freedom, kinematic chains, workspace, and payload are introduced. This includes the presentation of medically used robots in different size scales, ranging from micro- and nanorobotics to minimally invasive continuum robotics and larger systems for robot-assisted surgery. Next, the different modules of the process chain for robot-assisted surgery are presented. It begins with medical imaging and the various tomographic techniques, explaining their physical principles and their diagnostic information about anatomy and pathology. Medical image processing, with a focus on segmentation, follows. This leads to the geometric 3D reconstruction of anatomical structures, forming the basis for an attributed patient model. The methods for registering preprocessed measurement data from different tomographic modalities are described. The various approaches for modeling tissue parameters complement the discussions, forming a complete patient model. The applications of the patient model in visualization and surgical planning are the next topic. The intraoperative part of the process chain includes registration, navigation, augmented reality, and surgical robotic systems. These are explained with fundamentals and application examples. Key points here include techniques for robot-assisted tissue cutting and approaches to micro- and nanosurgery. Finally, applications of machine learning in medical robotics are discussed. The lecture concludes with a brief discourse on specific safety issues and the legal aspects of medical products.
6	Learning objectives and skills	Students • have a good overview of existing surgical and medical robotic systems in research and practical applications. • understand the specific requirements of surgery for automation with robots. • can recognize basic kinematics and their relevance to medical requirements and applications. • are familiar with basic techniques for processing and using image data from different modalities and can apply them. • can design the complete workflow for a robot-assisted procedure.

7	Prerequisites	Recommended by the lecturer(s): Knowledge on robotics design, robot kinematics
8	Integration in curriculum	semester: 1
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable Written examination; duration 60 minutes
11	Grading procedure	Variable (100%) Written examination 100%
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 44159	Surgical Technologies Innovation	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Franziska Mathis-Ullrich
5	Contents	The module involves theoretical and practical course work. Interactive lectures will provide introduction to medical technologies, surgical robotics and machine learning for surgical applications. In addition, through lectures, experts from several surgical disciplines (e.g. Neurosurgery, Abdominal surgery, Urology, Orthopedic surgery) will introduce their surgical fields and point out current challenges in their respective fields. During hospitalizations at the operation room, students gain understanding about surgeries and are to identify problems and worksteps that may be solved and/or supported by novel medical technologies. In exercise teams, the students will research and develop technologies to support surgeons in the respective surgical discipline and evaluate them in the lab. If successful, students are encouraged to submit and present their work at a medical technologies conference.
6	Learning objectives and skills	Students • are able to identify challenges in surgical procedures through observation and interviews • are able to solve a practical problem from the field of medical technology independently. • are able to specify and implement hardware and software required to solve a given problem. • apply basic knowledge to a problem and develop solution strategies. • are able to solve a problem alone or as part of a team. • have knowledge of the phases of a project, time, and resource management. • are confident in the use of software development tools, source code management, and documentation. • are able to convey complex technical content in a scientific report and presentation.
7	Prerequisites	• ◦ AI in Medical Engineering, ◦ Robotics in Surgery and Diagnostics, ◦ Empirical Research Methods in Medical Engineering • ◦ AI, ◦ robotics ◦ surgical application will be an advantage. • A high degree of motivation and independency is expected.

		The number of accepted students is limited.
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable Written report and presentation; attendance at exercises is mandatory
11	Grading procedure	Variable (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
14	Module duration	1 semester
15	Teaching and examination language	german or english
16	Bibliography	

Human-system Interfaces - Seminar & laboratory

1	Module name 92507	Laborpraktikum Human-Robot Interaction Laboratory course Human-Robot Interaction	2,5 ECTS
2	Courses / lectures	Praktikum: Human-Robot Interaction Laboratory - Group A Tuesday (2 SWS) Praktikum: Human-Robot Interaction Laboratory - Group B Thursday (2 SWS) Attendance is required for all six experiments.	2,5 ECTS 2,5 ECTS
3	Lecturers	Martin Rohrmüller Prof. Dr.-Ing. Philipp Beckerle	

4	Module coordinator	Prof. Dr.-Ing. Philipp Beckerle
5	Contents	Six experiments are completed in the HRI (Human Robot Interaction) practical course. After an introduction to ROS and Python, three experiments are carried out with a Franka-Emika lightweight robot and two experiments with a humanoid NAO robot. The structure of each experiment is composed of a preparation phase, an execution phase and a reflection phase, in which the participants work in groups on tasks to create a complex application on each of the platforms. • Introduction to the Robot Operating System (ROS) • Introduction to Python • Teleoperation of the lightweight robot • Collaboration with the lightweight robot • Collision detection and reconfiguration with the lightweight robot • Object recognition with the humanoid robot as platform • Object recognition with neural networks
6	Learning objectives and skills	Upon completion of the lab course, students will be able to understand the basic concepts of ROS and design applications of a lightweight robot in terms of human-machine interaction. They will learn how humanoid robots work and assess their current state of the art.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Human-system Interfaces - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement Students are required to complete the practical assignment of each experiment within 4 hours. The course is considered passed if all six experiments are successfully completed within the specified time. Attendance accounts to 16h and self-study to 59h.
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester

15	Teaching and examination language	english
16	Bibliography	

1	Module name 92346	Seminar Autonomous Systems and Mechatronics Seminar: Autonomous systems and mechatronics	2,5 ECTS
2	Courses / lectures	Seminar: Seminar Autonomous Systems and Mechatronics (2 SWS) Attendance is required for all sessions in presence.	2,5 ECTS
3	Lecturers	Yongxu Ren Prof. Dr.-Ing. Philipp Beckerle	

4	Module coordinator	Prof. Dr.-Ing. Philipp Beckerle
5	Contents	In the seminar, students will analyze, present. and discuss recent research topics in autonomous systems and mechatronics. This will comprise mechatronic component, system, and control design as well as advanced methods aiming at autonomous operation. Besides reflecting contemporary literature, the students are asked to conclude and suggest directions for future research.
6	Learning objectives and skills	On successful completion of this module, students will be able to comprehend and convey recent research challenges in the area of autonomous system and mechatronics. Moreover, they are prepared to infer future research lines from recent developments.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Human-system Interfaces - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Seminar achievement Attendance is required for all 4 sessions in presence totaling to 8h. Self-study accounts to 67h. The final presentation (15 min + 10 min Q&A) accounts to 60% of the final grade and the final report to the remaining 40% (at least 4 pages).
11	Grading procedure	Seminar achievement (100%)
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 10 h Independent study: 65 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 47667	Seminar Human-Robot Interaction Seminar: Human-robot interaction	2,5 ECTS
2	Courses / lectures	Seminar: Seminar Mensch-Roboter-Interaktion (2 SWS) Attendance is required for all sessions in presence.	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Philipp Beckerle Maria Luna Ghanime Rodrigo Jose Velasco Guillen	

4	Module coordinator	Prof. Dr.-Ing. Philipp Beckerle
5	Contents	In the seminar, students will analyze, present, and discuss recent research topics in human-robot-interaction. This will comprise aspects of cognitive and physical human-robot interaction and related topics of human and engineering sciences. Besides reflecting contemporary literature, the students are asked to conclude and suggest directions for future research.
6	Learning objectives and skills	On successful completion of this module, students will be able to comprehend and convey recent research challenges in the area of human-robot interaction. Moreover, they are prepared to infer future research lines from recent developments.
7	Prerequisites	None
8	Integration in curriculum	semester: 3
9	Module compatibility	Human-system Interfaces - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Seminar achievement Attendance is required for all 4 sessions in presence totaling to 8h. Self-study accounts to 67h. The final presentation (15 min + 10 min Q&A) accounts to 60% of the final grade and the final report to the remaining 40% (at least 4 pages).
11	Grading procedure	Seminar achievement (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 10 h Independent study: 65 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Selected research articles.

1	Module name 47595	Seminar The why and how of human gait simulations Seminar: The why and how of human gait simulations	5 ECTS
2	Courses / lectures	Seminar: The why and how of human gait simulations (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Anne Koelewijn	

4	Module coordinator	Prof. Dr. Anne Koelewijn
5	Contents	In this module, students will analyse, present and discuss issues and topics concerning the usage of biological signals in rehabilitation and assistive robotics, including the correct placement and use of the associated sensors, the techniques to condition the signals, sensor fusion, feature extraction and the usage of machine learning applied to such kind of signals. Besides reflecting on contemporary literature, the students are asked to draw own conclusions and suggest directions for future research.
6	Learning objectives and skills	On successful completion of the module, students will be familiar with sensors and signals used in rehabilitation and assistive robotics, both theoretically and practically. They will also be able to deduce potential new research lines from recent developments.
7	Prerequisites	Recommended: basic maths, especially statistics; fundamentals of signal processing and machine learning.
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Human-system Interfaces - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Seminar achievement
11	Grading procedure	Seminar achievement (100%)
12	Module frequency	no Module frequency information available!
13	Workload in clock hours	Contact hours: 30 h Independent study: 120 h
14	Module duration	1 semester
15	Teaching and examination language	
16	Bibliography	• [2002] Control of Multifunctional Prosthetic Hands by Processing the Electromyographic Signal, M. Zecca, S. Micera, M. C. Carrozza and P. Dario. • [2010] Control of Hand Prostheses Using Peripheral Information, S. Micera, J. Carpaneto and S. Raspopović. • [2015] A survey of sensor fusion methods in wearable robotics, D. Novak and R. Riener

Networking & Collaboration - Core modules

1	Module name 47800	Digital Communications Digital communications	5 ECTS
2	Courses / lectures	Vorlesung: Digital Communications (3 SWS) Übung: Tutorial for Digital Communications (1 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Laura Cottatellucci Brikena Kaziu	

4	Module coordinator	Prof. Dr. Laura Cottatellucci
5	Contents	Alle modernen Kommunikationssysteme basieren auf digitalen Übertragungsverfahren. Diese Vorlesung befasst sich mit den Grundlagen der Analyse und des Entwurfs digitaler Sender und Empfänger. Dabei wird zunächst von einem einfachen Kanalmodell bei dem das Empfangssignal nur durch additives weißes Gaußsches Rauschen gestört wird ausgegangen. Im Verlauf der Vorlesung werden aber auch Kanäle mit unbekannter Phase sowie verzerrende Kanäle betrachtet. Behandelt werden unter anderem digitale Modulationsverfahren (z.B. Pulsamplitudenmodulation (PAM), digitale Frequenzmodulation (FSK), und Kontinuierliche-Phasenmodulation (CPM)), Orthogonalkonstellationen, das Nyquistkriterium in Zeit- und Frequenzbereich, optimale kohärente und inkohärente Detektions- und Decodierungsverfahren, die Signalraumdarstellung digital modulierter Signale, verschiedene Entzerrungsverfahren, und Mehrträger-Übertragungsverfahren. --- Modern communication systems are based on digital transmission methods. This course covers basics of analysis and design of digital transmitters and receivers. Initially, we consider a simple channel model whose received signal is impaired only by additive white Gaussian noise. Then, we extend fundamental concepts to channels with unknown phases and distortion. Additionally, we treat digital modulation techniques, e.g., pulse amplitude modulation (PAM), digital frequency modulation (FSK) and continuous-phase modulation (CPM), and orthogonal constellations. The Nyquist criterion in time and frequency domain, optimal coherent and incoherent detection and decoding methods, signal space representations of digitally modulated signals, various equalization methods, and multicarrier transmission methods are also discussed.
6	Learning objectives and skills	Die Studierenden - analysieren und klassifizieren digitale Modulationsverfahren hinsichtlich ihrer Leistungs- und Bandbreiteneffizienz sowie ihres Spitzenwertfaktors, - ermitteln notwendige Kriterien für impulsinterferenzfreie Übertragung, - charakterisieren digitale Modulationsverfahren im Signalraum, - ermitteln informationsverlustfreie Demodulationsverfahren, - entwerfen optimale kohärente und inkohärente Detektions- und Decodierungsverfahren,

		• vergleichen verschiedene Entzerrungsverfahren hinsichtlich deren Leistungsfähigkeit und Komplexität, • entwerfen einfache digitale Übertragungssysteme mit vorgeschriebenen Leistungs- und Bandbreiteneffizienzen sowie Spitzenwertfaktoren. • -- The students • analyze and classify digital modulation techniques in terms of performance and bandwidth efficiency as well as crest factor, • determine necessary criteria to design impulses for interference-free transmission, • characterize digital modulation methods in signal space, • determine information loss-free demodulation methods, • design optimal coherent and incoherent detection and decoding methods, • compare different equalization methods in terms of performance and complexity, • design simple digital transmission systems with prescribed power and bandwidth efficiency and crest factor.
7	Prerequisites	None
8	Integration in curriculum	semester: 5
9	Module compatibility	Networking & Collaboration - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 48410	Information Theory and Coding Information theory and coding	5 ECTS
2	Courses / lectures	Übung: Tutorial for Information Theory and Coding (1 SWS) Vorlesung: Information Theory and Coding (3 SWS)	- 5 ECTS
3	Lecturers	Dr. Sebastian Lotter	

4	Module coordinator	Prof. Dr.-Ing. Ralf Müller
5	Contents	1. Introduction: binomial distribution, (7,4)-Hamming code, parity-check matrix, generator matrix 2. Probability, entropy, and inference: entropy, conditional probability, Bayes law, likelihood, Jensens inequality 3. Inference: inverse probability, statistical inference 4. The source coding theorem: information content, typical sequences, Chebychev inequality, law of large numbers 5. Symbol codes: unique decidability, expected codeword length, prefix-free codes, Kraft inequality, Huffman coding 6. Stream codes: arithmetic coding, Lempel-Ziv coding, Burrows-Wheeler transform 7. Dependent random variables: mutual information, data processing lemma 8. Communication over a noisy channel: discrete memory-less channel, channel coding theorem, channel capacity 9. The noisy-channel coding theorem: jointly-typical sequences, proof of the channel coding theorem, proof of converse, symmetric channels 10. Error-correcting codes and real channels: AWGN channel, multivariate Gaussian pdf, capacity of AWGN channel 11. Binary codes: minimum distance, perfect codes, why perfect codes are bad, why distance isnt everything 12. Message passing: distributed counting, path counting, low-cost path, min-sum (=Viterbi) algorithm 13. Exact marginalization in graphs: factor graphs, sum-product algorithm 14. Low-density parity-check codes: density evolution, check node degree, regular vs. irregular codes, girth 15. Lossy source coding: transform coding and JPEG compression -- 1. Einleitung: Binomialverteilung, (7,4)-Hamming-Code, Paritätsmatrix, Generatormatrix 2. Wahrscheinlichkeit, Entropie und Inferenz: Entropie, bedingte Wahrscheinlichkeit, Bayessches Gesetz, Likelihood, Jensensche Ungleichung 3. Inferenz: Inverse Wahrscheinlichkeit, statistische Inferenz 4. Das Quellencodierungstheorem: Informationsgehalt, typische Folgen, Tschebyschevsche Ungleichung, Gesetz der großen Zahlen 5. Symbolcodes: eindeutige Dekodierbarkeit, mittlere Codewortlänge, präfixfreie Codes, Kraftsche Ungleichung, Huffmancodierung

		6. Stromcodes: arithmetische Codierung, Lempel-Ziv-Codierung, Burrows-Wheeler-Transformation 7. Abhängige Zufallsvariablen: Transinformation, Datenverarbeitungslemma 8. Kommunikation over gestörte Kanäle: diskreter gedächtnisloser Kanal, Kanalcodierungstheorem, Kanalkapazität 9. Das Kanalcodierungstheorem: verbundtypische Folgen, Beweis des Kanalcodierungstheorems, Beweis des Umkehrsatzes, symmetrische Kanäle 10. Fehlerkorrigierende Codes und reale Kanäle: AWGN-Kanal, mehrdimensionale Gaußsche WDF, Kapazität des AWGN-Kanals 11. Binäre Codes: Minimaldistanz, perfekte Codes, Warum perfekte Codes schlecht sind, Warum Distanz nicht alles ist 12. Nachrichtenaustausch: verteiltes Zählen, Pfadzählen, günstigster Pfad, Minimumsummenalgorithmus 13. Exakte Marginalisierung in Graphen: Faktorgraph, Summenproduktalgorithmus 14. LDPC-Codes: Dichteevolution, Knotenordnung, reguläre und irreguläre Codes, Graphumfang 15. Verlustbehaftete Quellencodierung: Transformationscodierung und JPEG-Kompression
6	Learning objectives and skills	The students apply Bayesian inference to problems in both communications and everyday's life. The students explain the concept of digital communications by means of source compression and forward-error correction coding. For the design of communication systems, they use the concepts of entropy and channel capacity. They calculate these quantities for memoryless sources and channels. The students proof both the source coding and the channel coding theorem. The students compare various methods of source coding with respect to compression rate and complexity. The students apply source compression methods to measure mutual information. The students factorize multivariate functions, represent them by graphs, and marginalize them with respect to various variables. The students explain the design of error-correcting codes and the role of minimum distance. They decode error-correcting codes by means of maximum-likelihood decoding and message passing. The students apply distributed algorithms to problems in both communications and everyday's life. The students improve the properties of low-density parity-check codes by widening the girth and/or irregularity in the degree distribution. The students transform source images into the frequency domain to improve lossy compression. -- Die Studierenden wenden Bayessche Inferenz auf Probleme in der Nachrichtentechnik und im Alltagsleben an.

		Die Studierenden erklären die konzeptuelle Trennung von digitaler Übertragung in Quellen- und Kanalcodierung. Kommunikationssysteme entwerfen sie unter Betrachtung von Entropie und Kanalkapazität. Sie berechnen diese Größen für gedächtnislose Quellen und Kanäle. Die Studierenden beweisen sowohl das Quellen- als auch das Kanalcodierungstheorem. Die Studierenden vergleichen verschiedenartige Quellencodierungsverfahren hinsichtlich Komplexität und Kompressionsrate. Die Studierenden verwenden Quellencodierverfahren zur Messung von Transinformation. Die Studierenden faktorisieren Funktionen mehrerer Veränderlicher, stellen diese als Graph dar und marginalisieren sie bezüglich mehrerer Veränderlicher. Die Studierenden erklären den Entwurf von Kanalcodes und den Einfluss der Minimaldistanz. Sie decodieren Kanalcodes gemäß maximaler Likelihood und Nachrichtenaustausch. Die Studierenden wenden verteilte Algorithmen auf Probleme der Nachrichtentechnik und des Alltagslebens an. Die Studierenden verbessern die Eigenschaften von LDPC-Codes durch Erhöhung des Umfangs und/oder durch irreguläre Knotenordnungsverteilungen. Die Studierenden transformieren Bildquellen zur Verbesserung verlustbehafteter Kompression in den Frequenzbereich.
7	Prerequisites	None
8	Integration in curriculum	semester: 5;6
9	Module compatibility	Networking & Collaboration - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Die Prüfung besteht aus einem 120-minütigen schriftlichen Test. The examination is a 120-minute written test.
11	Grading procedure	Written examination (100%)
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	MacKay, D.: Information Theory, Inference, and Learning Algorithms, Cambridge University Press, Cambridge, 2003.

1	Module name 96300	MIMO Communication Systems MIMO communication systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Robert Schober
5	Contents	Modern communication systems employ multiple antennas at the transmitter and/or receiver creating a multiple-input multiple-output (MIMO) system. This course covers the fundamental mathematical and communication theoretical concepts necessary for the design and analysis of MIMO communication systems. Relevant topics include MIMO Channel Capacity, Receive Diversity, Transmit Diversity, Space-Time Coding, Spatial Multiplexing, MIMO Transceiver Design, Multi-user MIMO, Massive MIMO, Relay-based MIMO, and applications in modern communication systems.
6	Learning objectives and skills	The students • learn about different MIMO channel models, • analyze MIMO communication systems with respect to their channel capacity and reliability, • determine MIMO figures of merit such as coding gain, diversity gain, and multiplexing gain, • compare and evaluate different MIMO receiver designs, • characterize the rate region of multiuser systems, • analyze massive MIMO systems, • discuss the advantages and disadvantages of different relay network architectures. Die Studierenden • lernen verschiedene MIMO-Kanalmodelle kennen, • analysieren MIMO-Kommunikationssysteme hinsichtlich der Kanalkapazität und Zuverlässigkeit, • ermitteln MIMO-Kenngrößen wie Codierungsgewinn, Diversitätsgewinn und Multiplexgewinn, • vergleichen und beurteilen verschiedene MIMO-Empfangsstrategien, • charakterisieren die Ratenregion von Mehrteilnehmersystemen, • analysieren Massive-MIMO-Systeme, • diskutieren die Vor- und Nachteile verschiedener Relaisnetzwerkarchitekturen.
7	Prerequisites	Basic course in communications
8	Integration in curriculum	semester: 6
9	Module compatibility	Networking & Collaboration - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242

10	Method of examination	Written or oral (90 minutes) Written exam (Klausur), 90 minutes.
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 668129	Machine Learning in Communications Machine learning in communications	5 ECTS
2	Courses / lectures	Vorlesung: Machine Learning in Communications (4 SWS) Übung: Tutorial for Machine Learning in Communications (0 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Laura Cottatellucci Christian Forsch	

4	Module coordinator	Prof. Dr. Laura Cottatellucci
5	Contents	Recently, in many areas of wireless communications such as wireless sensor networks (WSNs), heterogeneous networks and complex ad hoc networks, distributed graph algorithms and machine learning on graphs are gaining relevance as fundamental tools in network analysis and information processing. This motivates to deliver a general introduction to fundamentals of machine learning such as detection of clusters on graphs. The introduction is followed by the application of machine learning to the design of physical and data layer techniques in wireless communications and in the optimization of mobile networks.
6	Learning objectives and skills	The students • know and explain the fundamentals of machine learning with special attention to machine learning over graphs. • apply these principles in the design and optimisation of wireless communications systems and mobile networks.
7	Prerequisites	None
8	Integration in curriculum	semester: 5
9	Module compatibility	Networking & Collaboration - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral The examination is a 30-minute oral exam. The examination language is English.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

Networking & Collaboration - Specialization modules

1	Module name 96310	Image and Video Compression Image and video compression	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Andre Kaup
5	Contents	Multi-Dimensional Sampling - Sampling theorem revisited, 2D sampling, spatiotemporal sampling, motion in 3D sampling Entropy and Lossless Coding - Entropy and information, variable length codes, Huffman coding, unary coding, Golomb coding, arithmetic coding Statistical Dependency - Joint entropy and statistical dependency, run-length coding, fax compression standards Quantization - Rate distortion theory, scalar quantization, Lloyd-Max quantization, entropy coded scalar quantization, embedded quantization, adaptive quantization, vector quantization Predictive Coding - Lossless predictive coding, optimum 2D linear prediction, JPEG-LS lossless compression standard, differential pulse code modulation (DPCM) Transform Coding - Principle of transform coding, orthonormal transforms, Karhunen-Loève transform, discrete cosine transform, bit allocation, compression artifacts Subband Coding - Principle of subband coding, perfect reconstruction property, discrete wavelet transform, bit allocation for subband coding Visual Perception and Color - Anatomy of the human eye, sensitivity of the human eye, color spaces, color sampling formats Image Coding Standards - JPEG and JPEG2000 Interframe Coding - Interframe prediction, motion compensated prediction, motion estimation, motion compensated hybrid coding Video Coding Standards - H.261, H.263, MPEG-1, MPEG-2 / H.262, H.264 / MPEG-4 AVC, H.265 / MPEG-H HEVC
6	Learning objectives and skills	The students - visualize multi-dimensional sampling and the influence of motion within the video signal - differentiate and evaluate different methods for lossless image and video coding

		• understand and analyze mutual entropy and statistical dependencies in image and video data • determine scalar and vector quantization for different optimization criteria (minimum mean square error, entropy coding, embedded quantization) • determine and evaluate optimal one-dimensional and two-dimensional linear predictor • apply prediction and quantization for a common DPCM system • understand the principle and effects of transform and subband coding for image data including optimal bit allocation • describe the principles of the human visual system for brightness and color • analyze block diagrams and the functioning of hybrid coders and decoders for video signals • know the prevailing international standards of ITU and MPEG for image and video compression.
7	Prerequisites	Lectures on Signal and Systems and Communication Systems strongly recommended
8	Integration in curriculum	semester: 2
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written or oral (90 minutes) Written exam of 90 min duration
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	J.-R. Ohm: Multimedia Communications Technology, Springer, 2004

1	Module name 700506	Communications Systems Design Communications systems design	5 ECTS
2	Courses / lectures	Vorlesung: Communications Systems Design (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Georg Fischer	

4	Module coordinator	Prof. Dr.-Ing. Georg Fischer Prof. Dr.-Ing. Norman Franchi Torsten Reißland Torsten Reißland
5	Contents	Learning based on LabVIEW communications and NI USRP: Introduction to USRP including hardware blocks of Tx/Rx chains Getting familiar with LabVIEW communications environment and controlling VIs (Panel, diagram, etc.) and fundamentals of LabVIEW programming: data types, arrays, flow control (for/while loop), clusters, case structures, signal sources, sinks, signal processing tools, filters, time/ frequency domain analysis, etc. Transmission and reception of analog modulation schemes: AM/DSB-SC and FM Implementation of digital modulation schemes: ASK, FSK, BPSK, QPSK, 16-QAM, etc. Digital Tx/Rx: symbol mapping, upsampling/downsampling, pulse shaping (rectangular, Gaussian, RRC), matched filtering, pulse alignment, synchronization, and detection Phase synchronization, FDM and image rejection algorithm Eye diagram analysis: ISI, clock jitter, optimal sampling time, detection threshold Power control for over-the-air transmission in sub-6 GHz ISM bands and analysis on fading and multipath propagation effects Channel estimation, equalization (decision directed, linear LS, adaptive LMS), modelling: coherence bandwidth and propagation delay Learning based on MATLAB and USRPs (Communications toolbox and SDR support packages): OFDM Tx/Rx with frequency domain equalization (FDE) and synchronization (training sequence and frame detection) LTE downlink transmission (MIMO) including system information blocks (SIB) and spectrum analysis including estimation/calibration of carrier frequency offset (CFO) Impairments/distortion analysis: ACPR, EVM tool: IQ offset errors, phase noise, PA nonlinearity, etc. Learning based on GNU Radio and RTL-SDR: Introduction to GNU Radio with RF prototyping demonstration Spectrum analyzer implementation: RBW, VBW, sweep time, and phase noise Small Project/assignment for students
6	Learning objectives and skills	Students Can bridge the gap between communications theory, analog/digital baseband, and RF design

		Can develop quick and flexible prototypes for real-time communications systems and standards using SDR solutions Can determine the design parameters and assess the interaction between various analog and digital parts Can create efficient Tx/Rx programs and signal processing algorithms in LabVIEW, MATLAB, and GNU Radio Can implement channel estimation and equalization algorithms in TDD and FDD systems Can demonstrate MIMO and OFDM based systems like LTE and beyond Can quantify and evaluate system performance using EVM and impairments analysis
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 45 h Independent study: 30 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 636348	Cyber-Physical Systems Cyber-physical systems	5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Dr.-Ing. Torsten Klie
5	Contents	Klassische Computersysteme zeichnen sich durch eine strikte Trennung von realer und virtueller Welt aus. Moderne Steuerungssysteme, die z.B. in modernen Fahrzeugen verbaut sind und die aus einer Vielzahl von Sensoren und Aktoren bestehen, entsprechen diesem Bild nur sehr eingeschränkt. Diese Systeme, oft "Cyber-Physical Systems (CPS)" genannt, erkennen ihre physische Umgebung, verarbeiten diese Informationen und können die physische Umwelt auch koordiniert beeinflussen. Hierzu ist eine starke Kopplung von physischem Anwendungsmodell und dem Computer-Steuerungsmodell nötig. Im Unterschied zu Eingebetteten Systemen bestehen CPS meist aus vielen vernetzten Komponenten, die sich selbständig untereinander koordinieren. Diese Vorlesung spannt den Bogen von kontrolltheoretischen Grundlagen über Selbstorganisationsprinzipien bis hin zu visionären Anwendungen aus den Bereichen Verkehr und Medizintechnik. Ferner werden Entwurfsmethoden für Cyber-Physical Systems vorgestellt.
6	Learning objectives and skills	Die Studierenden erläutern, was Cyber-Physical Systems sind und auf welchen technologischen Grundlagen sie aufbauen, insbesondere in den Bereichen Regelungstechnik, Ablaufplanung, Kommunikation und Selbstorganisation bewerten CPS in verschiedenen Anwendungsgebieten stellen den Entwurfsprozess von CPS dar, insbesondere die Modellierung und die grundlegende Programmierung entdecken wesentliche Herausforderungen beim Entwurf, Ausbringung und Einsatz von CPS.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h

14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	• Andrea Bondavalli, Sara Bouchenak und Hermann Kopetz (Hrsg.) Cyber-Physical Systems of Systems: Foundations – A Conceptual Model and Some Derivations: The AMADEOS Legacy. Springer 2016. • Otto Föllinger Regelungstechnik. Hüthig 1992. • Hilmar Jaschek und Holger Voos Grundkurs der Regelungstechnik. Oldenbourg 2010. • Jörg Kahlert Crash-Kurs Regelungstechnik. VDE Verlag 2010. • Peter Marwedel Embedded Systems Design – Embedded Systems Foundations of Cyber-Physical Systems, and the Internet of Things, 4. Auflage. Springer 2021 • André Platzner Logic Foundations of Cyber-physical Systems. Springer 2018. • Wolfgang Schneider Praktische Regelungstechnik. Vieweg +Teubner 2008. • Walid M. Taha, Abd-Ehamid M. Taha und Johan Thunberg Cyber-physical Systems – A Model-based Approach. Springer 2021.

1	Module name 43141	Mobile Communications Mobile communications	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Ralf Müller
5	Contents	History of mobile communications, cellular systems, sectorization, spectral efficiency, co-channel interference, adjacent-channel interference, near-far effect, cellular network architecture, antenna types and parameters, free space propagation, reflection, attenuation, diffraction, scattering, classification of channel models, ground reflection model, Okumura-Hata model, shadowing, narrow-band fading, time-variant channels, scattering function, delay-Doppler spectrum, diversity principles, combining methods, diversity gain, multiplexing, duplexing, digital modulation, Gaussian filtered minimum shift keying, basics of channel coding, interleaving, global system for mobile communications, physical versus logical channels, frame structure, call set-up, synchronization, channel estimation, hand-off
6	Learning objectives and skills	The students explain the cellular structure of mobile communication systems. They students explain the physical mechanics of radio wave propagation in the cm-band. The students explain the GSM cellular communications standard. The students discuss the pros and cons of several multiple-access and duplexing methods. The students discuss the pros and cons of several modulation and coding formats. The students decide which antenna type is suitable for a given morphological structure of the environment. The students predict the amplitude and dynamic of the attenuation between a mobile transmitter and a fixed receiver. The students utilize diversity methods to improve the link quality. The students determine the coverage probability of a given cellular communication system. The students collaborate on solving exercise problems. The students discuss which system solutions fit to which environments.
7	Prerequisites	None
8	Integration in curriculum	semester: 2
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h

14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Proakis, J.: Digital Communications, McGraw-Hill, 4th ed., 2001. Rappaport, T.: Wireless Communications: Principles & Practice, Prentice Hall, 2nd ed., 2001. Mouly, M., Paulet, M.: The GSM System for Mobile Communications, Cell & SYS, France, 1992. Goldsmith, A.: Wireless Communications, Cambridge Univ. Press, 2005.

1	Module name 687141	Multiusuer Information and Communications Theory Multiuser information and communications theory	5 ECTS
2	Courses / lectures	Übung: Tutorial for Multiuser Information and Communications Theory (1 SWS) Vorlesung: Multiuser Information and Communications Theory (3 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr.-Ing. Ralf Müller	

4	Module coordinator	Prof. Dr.-Ing. Ralf Müller
5	Contents	Linear vs. nonlinear multiple-access, CDMA as a canonical framework for any multiple-access schemes, optimum multiuser detection, linear multiuser detection, interference cancellation, rate region, multiuser source coding, time sharing, multiuser channel codes, multiple-access channel (MAC), capacity region, mutual information versus minimum-mean squared error, Gaussian MAC, power region, Gaussian vector MAC, source coding with side information, degraded broadcast channel, Gaussian broadcast-MAC duality, Gaussian vector broadcast channel, dirty-paper coding, physically degraded relay channel, scalar Gaussian relay channel, Gaussian interference channel, cut-set bound, network coding, fading channels, multiuser water filling, block fading, diversity, user diversity, capacity versus outage, near-far gain, dual antenna arrays
6	Learning objectives and skills	The students model any multiple access method as a special case of code-division multiple access. The students apply various algorithms for multiuser detection. The students explain various types of multiuser channels and their limits to transport information. The students explain the limits of distributed source coding algorithms. The students apply the cut-set bound. The students explain the method of dirty-paper coding. The students collaborate on solving exercise problems.
7	Prerequisites	Recommended: A basic course on information theory (can be taken in parallel)
8	Integration in curriculum	semester: 6
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral The examination is a 30-minute oral exam.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester

15	Teaching and examination language	english
16	Bibliography	• El Gamal, A., Kim, Y.: Network Information Theory, Cambridge University Press, 2011 • Cover, T., Thomas, J.: Elements of Information Theory, 2nd ed., Wiley, Hoboken, 2006 • Verdú, S.: Multiuser Detection, Cambridge Univ. Press, Cambridge, 1998 • Tse, D., Viswanath, P.: Fundamentals of Wireless Communications, Cambridge University Press, 2005.

1	Module name 451971	Random Matrices in Communications and Signal Processing Random matrices in communications and signal processing	5 ECTS
2	Courses / lectures	Vorlesung: Random Matrices in Communications and Signal Processing (2 SWS) Übung: Tutorial for Random Matrices in Communications and Signal Processing (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Ralf Müller	

4	Module coordinator	Prof. Dr.-Ing. Ralf Müller
5	Contents	Dual antenna arrays, compressive sensing, Wishart distribution, factor iid model, Kronecker model, convergence of random variables, semi-circle law, quarter circle law, full circle law, Haar distribution, Marchenko-Pastur distribution, Stieltjes transform, Girkos law, unitary invariance, freeness, free convolution, R-transform, free central limit theorem, free Poisson limit theorem, subordination, S-transform, R-diagonal random matrices, R-diagonal free convolution, Haagerup-Larsen law, operator-valued freeness, linearization of noncommutative polynomials, free Fourier transform, self-averaging properties, microscopic vs. macroscopic random variables, quenched random variable, a statistical physics point of view of digital systems, spin glasses, frozen disorder, replica method, replica continuity, replica symmetry, replica symmetry breaking, approximate message passing, classification of np-complete problems
6	Learning objectives and skills	The students find the limiting eigenvalue distributions of various types of random matrices. The students explain Stieltjes, R- and S-transforms. The students explain the limits of various types of fading channels. The students design coding and decoding methods for a given type of multiuser channel. The students perform additive and multiplicative free convolution. The students calculate the asymptotic eigenvalues distributions of given random matrix ensembles. The students construct random matrix ensembles with a given eigenvalue distribution. The students linearize matrix polynomials. The students derive the Boltzmann distribution. The students utilize saddle point integration. The students perform replica calculations. The students explain the meaning of replica symmetry breaking. The students collaborate on solving exercise problems.
7	Prerequisites	Recommended: Good skills in linear algebra, probability theory and complex analysis
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242

		Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral The examination is a 30-minute oral exam.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• Mingo, J., Speicher, R.: Free Probability and Random Matrices, Springer, 2017 • Couillet, R., Debbah, M.: Random Matrix Methods for Wireless Communications, Cambridge Univ. Press, Cambridge, 2011. • Mezard, M., Montanari, A.: Information, Physics, and Computation, Oxford Graduate Texts, 2009.

1	Module name 412023	Channel Coding on Graphs Channel coding on graphs	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Laura Cottatellucci
5	Contents	*Description* In today's communications world, channel coding underlies the physical layer of all major communication systems. For example: algebraic block coding (Reed-Solomon codes) are used in the CD and DVD standards; trellis coded modulation is used in line modems; low-density parity check codes (LDPC) are used in satellite communications (DVB-S2 standard), LAN (10GBase-T Ethernet) and wireless LAN (Wi-Fi 802.11); turbo codes are implemented in 3G/4G mobile communications (e.g. in UMTS and LTE) and in (deep space) satellite communications. Recently, polar codes have been adopted for the eMBB (Enhanced Mobile Broadband) control channels for the 5G NR (5th Generation New Radio) interface. Objective of this course is to provide an introductory but thorough background on codes over graphs and covers both classical convolutional codes and the modern theory of random-like codes with iterative decoding. Namely, LDPCs (Low Density Parity Check Codes, Turbo Codes, and Polar Codes. Students will acquire the fundamental knowledge to design and analyze performance of channel codes on graphs, as well as implement the corresponding encoders and decoders. *Technical Content* • Role of channel coding in a communication system. • Idealized channel models : the binary symmetric channel (BSC), the binary erasure channel (BEC), the constrained-input Gaussian channel. • Some preliminary basic concepts from linear block codes: Parity Check, Hamming distance, weight enumerating functions, performance evaluations, and performance bounds. • Factor graphs and belief propagation. • Binary random-like codes: LDPC codes and message-passing decoding, threshold behaviour of message passing decoding: density evolution analysis. Design of LDPC ensembles. • Polar Codes: Polarization, polar channel coding, performance, encoding and decoding. • Binary convolutional codes : the algebraic structure, the dynamic structure, Viterbi decoding, performance analysis via weight enumerating function, the forward-backward algorithm. • Other random-like codes: the Turbo Codes. Efficient decoding of Turbo Codes via forward-backward algorithm and interpretation via factor graphs. Performance analysis and exit charts.

6

Learning objectives and skills

The student

Uses idealized channel models (the binary symmetric channel (BSC), the binary erasure channel (BEC), the constrained-input

Gaussian channel) to compute their capacities

Contrasts soft output decoders with disjoint detection and decoding, maximum likelihood and maximum a posteriori decoders

Relates the concepts of Parity Check, Hamming distance, weight enumerating functions to the performance analysis of codes on graphs

Devises factor graphs of proposed communication systems

Assesses and justifies the applicability of belief propagation to given factor graphs

Assesses and justifies the applicability of message passing to codebooks defined in terms of Tanner graph or parity check matrix

Applies message passing to codebooks defined in terms of Tanner graph or parity check matrix

Analyses the performance of LDPC code decoding via density evolution

Computes exit charts for LDPC codes for the equations of the density evolution

Designs LDPC ensemble for a given channel to maximize the code rate

Justifies the design of LDPC codes via design of LDPC ensembles

Interprets convolutional codes as linear block codes

Compares algebraic and dynamic representations of convolutional codes

Computes steps of the Viterbi algorithm

Summarizes and justifies the fundamental structure of the Viterbi algorithm

Computes steps of the BCJR algorithm

Summarizes and justifies the fundamental structure of BCJR algorithm

Compares Viterbi and BCJR algorithms

Justifies low complexity and/or practical implementations of the Viterbi and the BCJR algorithm

Attaches a direct graph to a convolutional code and computes its transfer function

Assesses the performance of the Viterbi decoder via (bit) weight enumerating function based on the transfer function method

Interprets a BCJR algorithm as message passing over a factor graph

Combines encoders of convolutional codes to generate parallel concatenated codes with interleaver (turbo codes) of given rate

Combines encoders of convolutional codes to generate serial concatenated codes with interleaver (turbo codes)

Compares the key features of parallel concatenated codes with interleaver (turbo codes) to serial concatenated codes with interleaver (turbo codes)

Designs decoders for turbo codes utilizing coupled BCJR-based decoders for convolutional codes

Interprets turbo decoders as factor graphs and justifies their implementation via message passing

Assesses the performance of turbo codes using exit charts

		Formulates the concept of source polarization and relates it to polar channel coding Interprets polar channel coding as factor graphs Designs polar channel codes Argues about capacity achievability of polar channel codes
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes) Oral exam, 30 minutes
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 151664	Advanced Communication Networks Advanced communication networks	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Laura Cottatellucci
5	Contents	Telecommunications have become ubiquitous in daily life and wireless networks play a fundamental role thanks to their capability to support mobility. In a wireless communication, the concept of link does not exist. Users radiate energy and communicate through the superposition of each others transmissions which creates interference. Compared to wireline networks this scenario is extremely challenging but also offers unpredictable opportunities in the development of new technologies (massive MIMO, cognitive radio, etc.) and exploitation of new features, e.g., opportunistic communications and multiuser diversity. The exponentially increasing request of higher and higher throughput is satisfied densifying users and access points per unit area and allowing more and more interference while adopting advanced techniques and innovative resource allocation to mitigate the detrimental effects of interference. Objective of this course is to introduce the student to advanced techniques for coordinated medium access control and radio resource management in cellular systems. Power allocation, rate adaptation and scheduling will be discussed both in centralized and distributed settings. Some mathematical methods play a fundamental role in resource allocation, namely, classical Perron-Frobenius theory for nonnegative matrices, convex and nonconvex constrained optimization, distributed optimization and game theory. The course introduces the student to such methods and exemplifies their application to various resource allocation problems. Additionally, the course addresses relevant aspects of resource allocation in wireless networks such as fairness and cross-layer design. *Technical Content* • Properties and challenges of the wireless medium. • Basic concepts of communication networks: the layered architecture. • Evolution of wireless cellular network architectures: From Global System for Mobile to Advanced-Long Term Evolution. • Multiple Access Schemes: CSMA variants, TDMA, FDMA, CDMA, OFDMA, SC-FDMA, SDMA. • Uplink-downlink duality. • Opportunistic scheduling and multiuser diversity. • Advanced concepts: small cells and heterogeneous networks, relaying and cooperation, network coding, cognitive radio networks. • Basics of resource allocation: power allocation, rate adaptation, and scheduling.

		• Classical resource allocation techniques: Centralized and distributed power control based on the Perron-Frobenius theorem. • Fundamentals of convex constrained optimization and application to resource allocation. • Resource allocation and fairness. • Fundamentals of nonconvex optimization and relaxation techniques. • Applications of nonconvex optimization to resource allocation. • Fundamentals of distributed optimization and applications to resource allocation. • Fundamental concepts of game theory. • Resource contention via game theoretical methods.
6	Learning objectives and skills	The student • Describes and/or recognizes wireless channel models. • Criticizes the limits of a layered architecture in wireless systems. • Defends the use of cross-layer design in wireless network. • Appraises and compares the distribution of functionalities in network entities for different architectures. • Argue on the pros and contras of different multiple access schemes according to various criteria (e.g. spectral efficiency, power efficiency, robustness to interference). • Compares and contrasts micro-diversity and various macro-diversity schemes. • Computes the total rate of SDMA with various receivers. • Relates the multiple access in uplink to broadcasting in downlink and justifies the concept of uplink-downlink duality. • Uses uplink-downlink duality to design a precoder and allocate power. • Contrasts multiple access in uplink and broadcasting in downlink in terms of channel state acquisition both for TDD and FDD transmission. • Uses multiuser diversity for opportunistic scheduling. • Compares multiuser diversity for users having identical and different channel statistics. • Contrasts opportunistic scheduling in terms of channel state acquisition and feedback both for uplink and downlink and for both FDD and TDD transmission schemes. • Appraises the impact of multiple antennas on opportunistic scheduling. • Analyses different settings with interference in small cells and designs countermeasures. • Categorizes relaying schemes in LTE. • Analyses performance of relaying schemes. • Argues on possible improvements of relaying schemes via network coding and physical layer network coding. • Uses the Perron-Frobenius theorem to allocate power in a centralized manner.

		• Judges the feasibility of a power control problems and formulates alternative approaches in case of unfeasibility. • Uses the Perron-Frobenius theorem to design a distributed power control scheme. • Judges the convergences of distributed power control based on the Perron-Frobenius theorem and appraises the robustness of asynchronous power control. • Applies techniques of convex optimization to discriminate convex problems and determine necessary and/or sufficient conditions for global optimality. • Judges the applicability of KKT conditions and duality. • Uses KKT conditions to solve convex optimization problems. • Uses duality to solve convex optimization problems. • Applies convex optimization to resource allocation in wireless communications. • Compares different definitions of fairness and applies them to rate allocation. • Appraises the effect of channel knowledge at the transmitter on different fairness criteria. • Applies KKT conditions for opportunistic user scheduling. • Describes a proportional fair algorithm for opportunistic scheduling. • Applies relaxation to nonconvex quadratic constrained quadratic programming. • Formulates resource allocation problems as constrained optimization programming. • Contrasts various distributed optimization methods. • Applies the concept of best response to determine Nash equilibria. • Argues about existence and uniqueness of Nash equilibria. • Assesses if a given game is a potential game and solves it. • Defends the concept of Pareto optimality in resource allocation. • Contrasts the concepts of pure and mixed strategies in game theory. • Uses coupled constrained concave game to allocate powers in heterogeneous networks.
7	Prerequisites	Information Theory and Coding It is advisable that the student is familiar with basic concepts of Mobile Communications
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes) Oral exam, 30 minutes

11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 96850	Convex Optimization in Communications and Signal Processing Convex optimization in communications and signal processing	5 ECTS
2	Courses / lectures	Übung: Tutorial for Convex Optimization in Communications and Signal Processing (1 SWS) Vorlesung: Convex Optimization in Communications and Signal Processing (3 SWS)	- 5 ECTS
3	Lecturers	Yifei Wu apl. Prof. Dr. Wolfgang Gerstacker	

4	Module coordinator	apl. Prof. Dr. Wolfgang Gerstacker
5	Contents	Convex optimization problems are a special class of mathematical problems which arise in a variety of practical applications. In this course we focus on the theory of convex optimization, corresponding algorithms, and applications in communications and signal processing (e.g. statistical estimation, allocation of resources in communications networks, and filter design). Special attention is paid to recognizing and formulating convex optimization problems and their efficient solution. The course is based on the textbook "Convex Optimization" by Boyd and Vandenberghe and includes a tutorial in which many examples and exercises are discussed.
6	Learning objectives and skills	Students • characterize convex sets and functions, • recognize, describe and classify convex optimization problems, • determine the solution of convex optimization problems via the dual function and the KKT conditions, • apply numerical algorithms in order to solve convex optimization problems, • apply methods of convex optimization to different problems in communications and signal processing
7	Prerequisites	Signals and Systems, Communications
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written or oral (90 minutes) Die Prüfung ist eine 90-minütige schriftliche Klausur. Prüfungssprache ist Englisch. The examination is a 90-minute written test. The examination language is English.
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in winter semester

13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Boyd, Steven ; Vandenberghe, Lieven: Convex Optimization. Cambridge, UK : Cambridge University Press, 2004

1	Module name 43420	Transmission and Detection for Advanced Mobile Communications Transmission and detection for advanced mobile communications	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	apl. Prof. Dr. Wolfgang Gerstacker
5	Contents	The aim of this lecture is that the students acquire a basic knowledge of advanced transmission and detection techniques which are relevant to practical mobile communications systems. In the first part, it is shown how equalization schemes like decision-feedback equalization (DFE) and maximum-likelihood sequence estimation (MLSE) can be applied to the GSM/EDGE (Enhanced Data Rates for GSM Evolution) standard. Also, channel estimation for GSM/EDGE is covered. In GSM/EDGE, disturbance by interfering signals of other users is a further major problem. Therefore, interference cancellation algorithms are discussed in detail. The cases of several receive antennas and one receive antenna (single antenna interference cancellation) are distinguished. Several receive antennas can be also utilized for increasing the robustness against fading, applying diversity combination techniques. In the case of the availability of several transmit antennas only, additional space-time coding has to be used for realization of diversity gains. These aspects are also discussed in depth. Furthermore, an introduction to code-division multiple access (CDMA) transmission is given and it is shown how CDMA is applied in the UMTS system. The lecture is concluded by an introduction to digital transmission in the Long Term Evolution (LTE) system.
6	Learning objectives and skills	The students • describe basic equalization algorithms such as decision-feedback equalization (DFE) and maximum-likelihood sequence estimation (MLSE), • apply equalization algorithms to the GSM / Enhanced Data Rates for GSM Evolution (EDGE) mobile communication system, • formulate channel estimation methods for mobile communication systems, • characterize the interference problem in GSM / EDGE, - design interference suppression schemes for GSM/EDGE for receivers with a single antenna (single antenna interference cancellation) and multiple antennas, respectively, • characterize the performance of mobile communication networks for different reception schemes, • devise receivers for the realization of diversity gains for multiple receive antennas,

		• design space-time coding schemes for the realization of diversity gains for multiple transmit antennas, • describe transmission schemes which are based on code-division multiple access (CDMA), • apply reception techniques for CDMA to the UMTS system, • characterize the uplink transmission in the Long Term Evolution (LTE) system, • develop receivers for LTE. Die Studierenden • beschreiben grundlegende Entzerrverfahren wie entscheidungsrückgekoppelte Entzerrung (Decision-Feedback Equalization, DFE) und Maximum-Likelihood-Sequenzschätzung (Maximum-Likelihood Sequence Estimation, MLSE), • wenden Entzerrverfahren auf das GSM/EDGE (Enhanced Data Rates for GSM Evolution) Mobilfunksystem an, • formulieren Kanalschätzverfahren für Mobilfunksysteme, • charakterisieren das Interferenzproblem bei GSM/EDGE, • entwerfen Interferenzunterdrückungsverfahren für GSM/EDGE für Empfänger mit einer Antenne (Single Antenna Interference Cancellation) und mehreren Antennen, • bewerten die Leistungsfähigkeit von Mobilfunknetzen bei Einsatz verschiedener Empfangsverfahren, • konzipieren Empfänger zur Realisierung von Diversitätsgewinnen bei empfangsseitiger Antennendiversität • entwerfen Space-Time-Codiervverfahren zur Realisierung von Diversitätsgewinnen bei sendeseitiger Antennendiversität, • beschreiben auf Code-Division Multiple Access (CDMA) basierende Übertragungsverfahren, • wenden Empfangsverfahren für CDMA auf das UMTS-System an, • charakterisieren die Aufwärtsstrecke von Long Term Evolution (LTE), • entwerfen Empfänger für LTE.
7	Prerequisites	Systemtheorie, Nachrichtenübertragung
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written or oral Oral exam, 30 minutes.
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h

14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Lecture notes

1	Module name 965820	Approximate Computing Approximate computing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Joachim Falk Prof. Dr.-Ing. Jürgen Teich
5	Contents	Approximate Computing denotes a quite young research area that exploits the fact and capability of many applications and systems to tolerate imprecision and/or inexactness of computed results. Prominent areas of applications and novel techniques of computing approximate rather than exact results have brought up new implementations either at hardware and/or software levels for important emergent workloads such as searching, mining, image processing, and data retrieval. Although hardware technology is improving at a fast pace, energy and power are becoming more and more important constraints apart from exactly computing results in an acceptable amount of time. The main goals of approximate computing techniques are therefore to exploit the possible trade-off between power/energy consumption, accuracy, performance, and/or cost, e.g., utilized hardware resources. The purpose of the course approximate computing is to instruct students about the main ideas and concepts of approximate computing. This includes analyzing the trade-off between energy consumption, accuracy, run-time and hardware costs, concrete approximating techniques (e.g. approximate hardware synthesis, approximating algorithms) as well as theoretical background (determining the computational error and its complexity).
6	Learning objectives and skills	Fachkompetenz - Wissen • The students know the principles and benefits of Approximate Computing and when it is applicable. • The students know multiple error metrics and their semantic meaning. Fachkompetenz - Verstehen • The students understand the difference between the error metrics. • The students understand the principle of function falsification. • The students can apply the presented approximation techniques. Fachkompetenz - Anwenden • The students are capable of choosing the appropriate approximation technique based on given requirements.
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242

		Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable Oral exam in case of less than 20 participants (duration 30 mins). Otherwise, written exam (duration 90 mins).
11	Grading procedure	Variable (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Weitere Informationen: https://www.cs12.tf.fau.de/lehre/lehrveranstaltungen/vorlesungen/approximate-computing

1	Module name 96065	Next Generation Mobile Communication Systems: 5G-Advanced and 6G	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr. Stefan Brück apl. Prof. Dr. Wolfgang Gerstacker
5	Contents	Mobile communication plays a significant role in our daily life. Over the last three decades the mobile applications have been tremendously enhanced from voice only over mobile broadband to applications for the mobile internet. Currently, the next generation of cellular systems, the so-called 5th Generation (5G) is developed and first commercial 5G networks are expected to be deployed around mid of 2019. 5G will play an outstanding role for the Internet of Things and will redefine a wide range of industries by enabling new use cases. This lecture will provide the technical foundation of 4G (LTE) and 5G mobile communication systems with a focus on the radio access network and the PHY & MAC layer concepts.
6	Learning objectives and skills	The students • learn the technical history of mobile communications from 2nd (GSM), 3rd (UMTS), 4th (LTE) to the 5th (5G New Radio) Generation • understand the system and radio access network architecture of modern cellular communications systems and their enhancements towards 5G • compare the physical layer design of LTE and 5G New Radio • discuss how 5G networks are designed to address a wide range of diverse services and devices • analyze enhanced radio resource management concepts for use cases like cellular V2X (Vehicle-to-Everything) and NB-IoT (Narrowband Internet of Things) Die Studierenden • erfahren die technische Geschichte der Mobilkommunikation von der 2. (GSM), 3. (UMTS), 4. (LTE) bis zur 5. Generation (5G New Radio) • verstehen die System- und Funkzugangsnetzarchitektur moderner zellulärer Kommunikationssysteme und ihre Verbesserungen bei 5G • vergleichen das Design der physikalischen Übertragungsschicht von LTE und 5G New Radio • diskutieren, wie 5G-Netze für eine breite Palette unterschiedlicher Dienste und Geräte konzipiert sind • analysieren verbesserte Funkressourcenverwaltungskonzepte für Anwendungsfälle wie zellulare V2X (Vehicle-to-Everything)

		Kommunikation und das NB-IoT (Schmalband-Internet der Dinge)
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral The examination is a 30-minute oral exam. The examination language is English.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Lecture Notes 4G/5G Mobile Communication Systems

Networking & Collaboration - Seminar & laboratory

1	Module name 97651	Laborpraktikum Image and Video Compression Laborpraktikum Multimediakommunikation	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	PD Dr. Christian Herglotz
5	Contents	Content • Introduction to MATLAB • Implementation of the single video codec processing blocks • Integration into the video codec pipeline, tests, and extensions • Participation in a subjective video test of selected implementations • Presentation and discussion of the achieved results
6	Learning objectives and skills	The students • create a fully functional program using the programming environment MATLAB, • evaluate the processing blocks of a typical video codec, • design their own video codec and enhance it by extensions of their choice, • evaluate their implemented video codecs in a subjective comparison, • reflect upon the methods conveyed during the laboratory.
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement The lab course comprises ten sessions of four hours plus two sessions of two hours, which include 7 work packages, a subjective test, and a final presentation. Each work package requires a preparation in written form and will be checked and reviewed (pass/fail) before the start of each session. During each of the ten mandatory lab sessions, the students are required to work on programming tasks, which will be reviewed at the end of each session (pass/fail). After these ten programming sessions, a working video codec has to be handed in. Besides, the students have to participate a subjective test, where the codec results are evaluated. In the last session, each video codec has to be presented by the students. A certificate confirming the successful participation in the laboratory is received if all work packages have been sufficiently prepared and implemented, if the results of all work packages have been combined into a functional and

		running video codec which is suitable for subjective testing, if the subjective video test has been participated in, and if the final video codec has been presented during the final presentation.
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 45 h Independent study: 30 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	The lab course notes will be distributed during the introductory meeting.

1	Module name 92335	Lab Course Digital Signal Processing Laboratory course: Digital signal processing	2,5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Dr.-Ing. Heinrich Löllmann
5	Contents	In this laboratory course the theory from the lecture Digital Signal Processing is applied in practice, using the programming environment MATLAB. The topics include quantization, spectral analysis, FIR and IIR filter design, filter banks and adaptive filters. The course consists of 5 guided experiments in which students work on programming problems in groups of two, and a 5-day block course where each group works on an individual project from the field of digital signal processing. The preparation, as well as the results of the past experiment will be examined by a short test at the beginning of each experiment. For passing the lab course, a minimum number of points from the tests and the project is required. The course requires previous experience in MATLAB programming. It is possible to take the course in parallel to the DSP lecture, however, revision of the relevant lecture contents before each lab lesson, and participation in the DSP exercises and tutorials is required.
6	Learning objectives and skills	The students • create MATLAB programs for the each experiments and, by this, apply knowledge acquired in the DSP lecture and supplement course • analyze and evaluate the implemented algorithms • understand the requirements for practical realizations of algorithms for digital signal processing • reflect the learning progress during the lab course.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement
11	Grading procedure	Practical achievement (100%)
12	Module frequency	no Module frequency information available!
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	

16	Bibliography	• Rinderknecht, S. (2018). Einführung in die Mechatronik für den Maschinenbau. Shaker. • Isermann, R. (2007). Mechatronische Systeme: Grundlagen. Springer. • Janocha, H. (Ed.). (2013). Aktoren: Grundlagen und Anwendungen. Springer

1	Module name 92336	Seminar on Selected Topics of Multimedia Communications and Signal Processing Seminar: Selected topics of multimedia communications and signal processing	2,5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis
5	Contents	The Seminar on Selected Topics of Multimedia Communications and Signal Processing deals with current research topics in the area of multimedia communications and signal processing. In an introductory meeting, the course of the seminar is outlined and each participant selects one of the offered topics. The participant should become familiar with the assigned research topic and present it by a report and a talk at the end of the seminar with the support of a supervisor. In an intermediate meeting about 5 weeks after the introductory meeting, the participants give a brief presentation about their topics and show first results. In addition, hints for the preparation of the final talk are provided at this meeting. At the end of the semester, a final one-day meeting takes place where each participant presents his topic in a talk of 30 minutes followed by a discussion and questions from the audience. In addition, each participant has to submit a report of about 10 pages about his topic a few days before the final meeting.
6	Learning objectives and skills	The students • acquire and apply fundamental techniques to conduct a literature survey, and to prepare and present a technical topic • analyze and evaluate provided literature regarding the focus of their technical presentation • apply the knowledge acquired during their studies to deepen by themselves their technical focus • apply acquired knowledge to ask a presenter questions and to discuss the presentation • analyze and evaluate the presentations of other seminar participants.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Seminar achievement The given presentation and submitted report are included in the grade.
11	Grading procedure	Seminar achievement (100%)
12	Module frequency	Every semester

13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 92337	Smart City: Technologies and Systems Smart city: Technologies and systems	2,5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Prof. Dr.-Ing. Norman Franchi
5	Contents	- System thinking and integration - Interactions of hardware and software - Engineering design methods - Mechanical components - Energy conductors and transformers - Control elements and energy storages - Actuators - Electrodynamical and electromagnetic actuators - Fluid actuators and unconventional actuators - Sensors for measuring mechanical quantities - Control and information processing
6	Learning objectives and skills	On successful completion of this module, students will be able to: - Holistically understand mechatronic systems and optimize them using methods of system integration, control, and information processing. - Grundlegende mechanische Komponenten unterscheiden, charakterisieren, modellieren und im Rahmen des Systementwurfs auswählen und dimensionieren. - Distinguish, characterize, model, and select basic mechanical components to dimension them in terms of system design. - Describe electrodynamic, electromagnetic, fluid power, and unconventional actuators phenomenologically and mathematically to dimension them considering the overall system. - Describe sensors for measuring mechanical quantities phenomenologically and mathematically and dimension them taking into account the overall system.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Seminar achievement
11	Grading procedure	Seminar achievement (100%)
12	Module frequency	no Module frequency information available!
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	
16	Bibliography	Rinderknecht, S. (2018). Einführung in die Mechatronik für den Maschinenbau. Shaker.

	• Isermann, R. (2007). Mechatronische Systeme: Grundlagen. Springer. • Janocha, H. (Ed.). (2013). Aktoren: Grundlagen und Anwendungen. Springer

1	Module name 92527	Joint communications and sensing in wireless systems	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Norman Franchi
5	Contents	Radio sensing as an integrated capability of mobile communication networks have been identified as one of the key features of future 6G cellular systems. The main challenge here lies in the joint design of sensing and communications because mobile communications and radar, for example, are still designed as more or less independent technologies and systems with different design approaches. But, especially, the convergence of both technologies is of utmost interest, enabling benefits of integrated radio sensing like • sensing/radar-as-a-service, e.g., for object and obstacle detection, • joint signal processing frameworks for both target/environment detection/analysis and wireless communications, • highly synchronous operation of both technologies, • balancing dual-functional performance (coordination gain), • performing mutual assistance, • increasing resource efficiency using shared radio resources, • jamming detection and mitigation, • optimization of the network performance based on collected sensing information.
6	Learning objectives and skills	The design of JC&S-based wireless systems faces challenges in several electrical engineering areas, especially electronics design, radio-frequency (RF) design, information and communications technology (ICT) design, and system design. The seminar will examine the latest approaches, developments, and findings from research in the field of JC&S and Integrated Sensing and Communication (ISAC), respectively. And topics are offered across all of the aforementioned disciplines. Participants in this seminar are expected to have a basic knowledge of communications systems, such as those acquired in the Digital Communications and Fundamentals of Mobile Communications lectures.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Seminar achievement
11	Grading procedure	Seminar achievement (100%)

		Ca. halbstündiger Vortrag (60%), Ausarbeitung im Umfang von 7-10 Seiten (30%), aktive Teilnahme an der Diskussion anderer Vorträge (10%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 15 h Independent study: 60 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 97640	Laborpraktikum Mobilkommunikation Laboratory course: Mobile communication	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	apl. Prof. Dr. Wolfgang Gerstacker
5	Contents	Experiments • ◦ Characteristics of real mobile radio channels such as distortions and time variability ◦ models for mobile radio channels ◦ effects on the performance of a mobile radio system • ◦ Principles of different equalization methods ◦ equalizer design for GSM / EDGE ◦ simulation of trellis-based equalizers and visualization of the results • ◦ Principle of OFDM ◦ implementation-relevant aspects such as nonlinearities and peak-to-average-power ratio ◦ synchronization and equalization • MIMO Transmission (2 experiments) Versuche • ◦ Eigenschaften realer Mobilfunkkanäle wie Verzerrungen und Zeitvarianz, ◦ Modelle für Mobilfunkkanäle ◦ Auswirkungen auf die Leistungsfähigkeit eines Mobilfunksystems • ◦ Prinzipien verschiedener Entzerrverfahren ◦ Entzerrerdiseign für GSM/EDGE ◦ Simulation von trellisbasierten Entzerrern und Visualisierung der Ergebnisse • ◦ Prinzip von OFDM ◦ implementierungsrelevante Aspekte wie Nichtlinearitäten und Spitzenwertfaktor ◦ Synchronisation und Entzerrung • MIMO Übertragung (2 Versuche)
6	Learning objectives and skills	The students • describe the characteristics of real mobile radio channels, • explain the principles of OFDM and MIMO transmission systems,

		• implement equalization and adaptation procedures in Matlab, • perform radio network simulations, • learn to develop program code, • work together in a small team. Die Studierenden • charakterisieren die Eigenschaften realer Mobilfunkkanäle, • erklären die Funktionsweise von OFDM- und MIMO-Übertragungssystemen, • implementieren Entzerrungs- und Adaptionsverfahren in Matlab, • führen Funknetzsimulationen durch, • erlernen Programmcode eingeständig zu entwickeln, • arbeiten zielorientiert in einem kleinen Team zusammen.
7	Prerequisites	Vorkenntnisse aus Vorlesungen zu Nachrichtenübertragung (Communications) und Systemtheorie (Signals and Systems); Inhalte des Moduls "Mobile Communications" sind erforderliche Voraussetzung für eine sinnvolle Teilnahme;
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement • There are 8 experiments to be completed as well as an introduction to Matlab. These are described in the course materials. • Each experiment is to be prepared in writing at home. The preparation is checked and evaluated (sufficient/not sufficient) at the beginning of each experiment. • The results of each experiment are to be kept on the experimental computers during the execution of the experiment (programming tasks) and are checked at the end of the experiment (sufficient/not sufficient). Measurement results are to be documented in writing. • To pass the course, 8 sufficient experiment preparations and 8 sufficient experiment executions are required. • Es sind 8 Versuche sowie eine Einführung in Matlab zu absolvieren. Diese sind in den Kursunterlagen beschrieben. • Jeder Versuch ist zu Hause schriftlich vorzubereiten. Die Vorbereitung wird zu Beginn eines jeden Versuchs überprüft und bewertet (ausreichend/nicht ausreichend). • Die Ergebnisse eines jeden Versuchs sind während der Versuchsdurchführung auf den Versuchsrechnern vorzuhalten (Programmieraufgaben) und werden zum Abschluss des Versuchs überprüft (ausreichend/nicht ausreichend). Messergebnisse sind schriftlich zu dokumentieren.

		• Zum Bestehen des Praktikums sind 8 ausreichende Versuchsvorbereitungen und 8 ausreichende Versuchsdurchführungen notwendig.
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 35 h Independent study: 40 h
14	Module duration	1 semester
15	Teaching and examination language	german english
16	Bibliography	Skriptum zum Praktikum Mobilkommunikation

1	Module name 97520	Laborpraktikum Digitale Signalverarbeitung	2,5 ECTS
2	Courses / lectures	Praktikum: Lab Course Digital Signal Processing (2 SWS)	2,5 ECTS
3	Lecturers	Dr.-Ing. Heinrich Löllmann Prof. Dr.-Ing. Sebastian Schlecht	

4	Module coordinator	Prof. Dr.-Ing. Walter Kellermann
5	Contents	In this laboratory course the theory from the lecture Digital Signal Processing is applied in practice, using the programming environment MATLAB. The topics include quantization, spectral analysis, FIR and IIR filter design, filter banks and adaptive filters. The course consists of 5 guided experiments in which students work on programming problems in groups of two, and a 5-day block course where each group works on an individual project from the field of digital signal processing. The preparation, as well as the results of the past experiment will be examined by a short test at the beginning of each experiment. For passing the lab course, a minimum number of points from the tests and the project is required. The course requires previous experience in Python programming. It is possible to take the course in parallel to the DSP lecture, however, revision of the relevant lecture contents before each lab lesson, and participation in the DSP exercises is strongly recommended.
6	Learning objectives and skills	The students • create functional Python programs for the individual pre-drawn experiments and apply the knowledge acquired in the lecture and exercise • analyze and evaluate the algorithm they have implemented • understand the requirements of practical implementations of digital signal processing algorithms • reflect on their own learning process during the lab course.
7	Prerequisites	Strongly recommended are courses on signals and systems
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement Students must successfully complete 5 experiments and then work on a scientific project in groups of two, about which a 3 to 4-page documentation must be prepared. At the beginning of each experiment, the status of the preparation and the experimental results of the previous session are checked in a written test. To pass the lab course, a minimum number of points from the tests and the group project is required.

11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	The script for this lab course will be handed out at the introductory meeting. Moreover, the following books are recommended • J.G. Proakis, D.G. Manolakis: Digital Signal Processing. 4th edition. Prentice Hall, Englewood Cliffs, NJ, 2007. • A.V. Oppenheim, R.V. Schaffer: Digital Signal Processing. Prentice Hall, Englewood Cliffs, NJ, 1975. • K.D. Kammeyer, K. Kroschel: Digitale Signalverarbeitung: Filterung und Spektralanalyse mit MATLAB®-Übungen . 8. Aufl. Teubner, Stuttgart, 2012

1	Module name 92361	Smart City: Technologien und Systeme (TuS) Smart City: Technologies and systems (TuS)	2,5 ECTS
2	Courses / lectures	Hauptseminar: Smart City: Technologien und Systeme (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Norman Franchi	

4	Module coordinator	Prof. Dr.-Ing. Norman Franchi
5	Contents	Themen zur Auswahl: • Toward Location-Enabled IoT (LE-IoT): IoT Positioning Techniques, Error Sources, and Error Mitigation • Positioning Techniques in IoT • Error Sources in IoT Localization • Energy Consumption of eMTC and NB-IoT for Smart City Applications • Vehicular Fog Computing • (C-)V2X • Mioty als sichere Massive IoT/LPWAN Lösung • Open Data • Artificial Intelligence for efficient urban mobility • Augmented / Mixed / Extended Reality • Smart Parking Systems • 5G Private/Campus Networks • Microgrid Technology
6	Learning objectives and skills	Schlüsselwörter: Smart City, IoT, Campusnetze, LPWAN, NB-IoT, Microgrids, Smart Parking, C-V2X, 5G, Augmented / Mixed / Extended Reality, Misty, Vehicular Fog Computing • Die Studierenden erlangen grundlegende Kenntnisse in Recherche, Themenaufbereitung und Präsentationstechniken. • Die Studierenden erarbeiten Schwerpunkte technischer Zusammenhänge bei einem gegebenen Thema aus dem Gebiet der oben genannten Schlüsselwörter. • Die Studierenden vertiefen eigenständig einen technischen Schwerpunkt an Hand eines konkreten Beispiels einer zukünftigen Smart City. • Die Studierenden erlernen die Fähigkeit, sich in unbekannte Probleme einzuarbeiten und diese verständlich zu präsentieren. • Die Studierenden erlernen die Fähigkeit, als Zuhörer aktiv Fragen zu formulieren und technische Sachverhalte zu diskutieren.
7	Prerequisites	Sprache wird zu Vorlesungsbeginn vom Dozierenden festgelegt.
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Seminar achievement

		Seminararbeit (7 bis max. 10 Seiten A4)+Vortrag (20min + 10min), benotet
11	Grading procedure	Seminar achievement (100%) 60% Vortrag: Präsentation (20 Min.) plus Verteidigung (10 Min) 30% Ausarbeitung Seminararbeit 10% Aktive Teilnahme an der Diskussion anderer Vorträge
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 15 h Independent study: 60 h
14	Module duration	1 semester
15	Teaching and examination language	german or english
16	Bibliography	

1	Module name 93511	Praktikum Digitale Übertragung Digital communication Lab	2,5 ECTS
2	Courses / lectures	Praktikum: Praktikum Digitale Übertragung (3 SWS)	2,5 ECTS
3	Lecturers	Dr.-Ing. Clemens Stierstorfer	

4	Module coordinator	Prof. Dr.-Ing. Robert Schober
5	Contents	• 1 Digital Transmission of Data 1.1 Introduction, Background, Motivation 1.2 Purpose 1.3 Lab Environment 1.3.1 Transmitter 1.3.2 Receiver 1.4 Lab Exercises 1.4.1 Signal Generation at the Transmitter 1.4.2 (Coherent) Receivers for Pulse Amplitude Modulation 1.4.3 Transmission over the AWGN Channel • 2 Implementation of Transmitter and Receiver in Matlab 2.1 Introduction, Background, Motivation 2.2 Purpose 2.3 Lab Environment 2.3.1 Oversampling factor 2.3.2 Transmitter 2.3.3 Channel 2.3.4 Receiver 2.4 Lab Exercises 2.4.1 Transmitter 2.4.2 Channel 2.4.3 Receiver 2.4.4 BER calculation • 3 Variants of PAM-Transmission Schemes 3.1 Introduction, Background, Motivation 3.2 Purpose 3.3 Lab Environment 3.4 Lab Exercises 3.4.1 Basic Pulse Shape 3.4.2 Offset-QAM 3.4.3 Gaussian Minimum Shift-Keying 3.4.4 "Carrierless Amplitude and Phase Modulation • 4 OFDM 4.1 Introduction, Background, Motivation 4.1.1 Orthogonal Frequency-Division Multiplexing 4.1.2 Bit Loading 4.2 Purpose 4.3 Lab Environment 4.4 Lab Exercises 4.4.1 OFDM Transmitter 4.4.2 OFDM Receiver 4.4.3 Bit Loading • 5 Signal Space Representation 5.1 Introduction, Background, Motivation 5.2 Purpose 5.3 Lab Environment 5.4 Signal Space Representation 5.4.1 Orthogonality 5.4.2 Orthogonalization 5.5 Lab Exercises 5.5.1 Transmission with signal elements 5.5.2 Gram-Schmidt Procedure 5.5.3 Frequency Shift Keying • 6 Signal Processing in MIMO Systems 6.1 Introduction, Background, Motivation 6.2 Lab Environment 6.3 Lab Exercises 6.3.1 System Model 6.3.2 SISO 6.3.3 SIMO 6.3.4 MIMO
6	Learning objectives and skills	Die Studierenden vertiefen und erweitern ihre Kenntnisse der digitalen Nachrichtenübertragungsverfahren und der zugehörigen mathematischen Grundlagen anhand von Laborversuchen. Sie analysieren die Eigenschaften digitaler Pulsamplitudenmodulation und Varianten digitaler PAM. Dazu erzeugen sie im Labor mit der zur Verfügung gestellten Ausrüstung Sendesignale, die sie mit Hilfe üblicher Messgeräte (Oszilloskop, Effektivwertmesser) analysieren. Sie bauen Übertragungsstrecken für diese PAM-Verfahren auf und untersuchen die Effekte auf Empfängerseite. Sie bestimmen Störabstände, Fehlerraten usw. Des weiteren setzen die Studierenden ihre Kenntnisse der PAM-Übertragungsverfahren in selbst erstellte MATLAB-Routinen um, die die Simulation einer kompletten PAM-Übertragung mit Sender, Kanal

und Empfänger am Rechner modellieren. In einem weiteren Versuch ergänzen die Studierenden dieses Modell um eine OFDM-Übertragung und analysieren die Funktionsweisen von OFDM-Sendern und -empfängern. Sie untersuchen die Arbeitsweise von Ladealgorithmen bei OFDM-Systemen und implementieren diese in MATLAB.

Die Studierenden verdeutlichen sich das Konzept der Signalraumdarstellung in der digitalen Übertragung und implementieren ein beispielhaftes System in MATLAB. Sie erstellen Routinen zur Gram-Schmidt-Orthogonalisierung und zur FSK-Übertragung in MATLAB.

Die Studierenden analysieren einfache MIMO-Szenarien und implementieren entsprechende Empfängeralgorithmen.

Die Studierenden bereiten die Bearbeitung der Versuche im Labor anhand der ausgegeben Unterlagen und den Unterlagen zum Modul "Digitale Übertragung selbständig vor. Sie sind in der Lage, die für den jeweiligen Versuch notwendigen theoretischen Kenntnisse vor und während des Versuchs zu erklären und zur Lösung der Laboraufgaben und vorbereitenden Hausaufgaben einzusetzen. Sie dokumentieren die durchgeführten Versuche selbständig in ihren Unterlagen, so dass die Nachvollziehbarkeit der Arbeiten jederzeit gegeben ist. Die Arbeit im Labor organisieren sie in Kleingruppen (2-3 Personen) selbst. Sie erkennen die Notwendigkeit gewissenhafter Vorbereitung der Lerninhalte und disziplinierter Arbeitsweise im Labor.

Die Unterrichtssprache ist wahlweise Deutsch oder Englisch. Unterlagen werden ausschließlich auf Englisch zur Verfügung gestellt, weswegen die Studierenden die englischen Fachtermini kennen und nutzen.

Students deepen and extend their knowledge of digital message transmission methods and the associated mathematical principles by means of laboratory experiments. They analyze the properties of digital pulse amplitude modulation and variants of digital PAM. To this end, they generate transmit signals in the laboratory using the equipment provided and analyze them with the aid of standard measuring instruments (oscilloscope, rms meter). They build transmission links for these PAM methods and investigate the effects on the receiver side. They determine signal-to-noise ratios, error rates, etc.

Furthermore, the students implement their knowledge of the PAM transmission methods in self-created MATLAB routines, which model the simulation of a complete PAM transmission with transmitter, channel and receiver on the computer. In another experiment, students add an OFDM transmission to this model and analyze the operation of OFDM transmitters and receivers. They investigate the operation of loading algorithms in OFDM systems and implement them in MATLAB.

Students clarify the concept of signal space representation in digital transmission and implement an example system in MATLAB.

They create routines for Gram-Schmidt orthogonalization and FSK transmission in MATLAB. Students analyze simple MIMO scenarios and implement corresponding receiver algorithms.

The students independently prepare the experiments in the laboratory using the issued documents and the documents for the module "Digital

		Transmission". They are able to explain the theoretical knowledge required for the respective experiment before and during the experiment and use it to solve the laboratory tasks and preparatory homework. They independently document the experiments carried out in their records so that the supervisors can trace the work at any time. They organize the work in the laboratory themselves in small groups (2-3 persons). They recognize the necessity of certain preparation of the learning content and disciplined working methods in the laboratory. The language of instruction is either German or English. Documents are provided exclusively in English, which is why the students know and use the English technical terms.
7	Prerequisites	Das Praktikum richtet sich ausschließlich an Studierende, die das Moduls "Digitale Übertragung bereits absolviert haben oder es parallel zum Praktikum belegen. Die Inhalte dieses Moduls sind unabdingbare Grundlage und werden von den Studierenden beherrscht, d.h., sie können die entsprechenden Zusammenhänge erklären, Problemstellungen mathematisch formulieren und benötigte Größen berechnen. Grundlegende Kenntnisse der Software MATLAB sind notwendig (bspw. aus "Software für die Mathematik" oder "Simulationstools"). The lab course is aimed exclusively at students who have already completed the "Digital Transmission" module or who are taking it in parallel with the lab course. The contents of this module are an indispensable basis and are mastered by the students, i.e. they can explain the corresponding relationships, formulate problems mathematically and calculate required quantities. Basic mastery of the MATLAB software is necessary
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement • There are 5 experiments to complete as well as an online test on Matlab knowledge and basic knowledge of digital communications. The details are described in the course materials. • Each experiment must be prepared in writing at home. The preparation will be checked and evaluated at the beginning of each experiment (sufficient/insufficient). • The results of each experiment must be recorded on the experimental computers during the execution of the experiment (programming tasks) and are checked at the end of the experiment (sufficient/insufficient). The measured results must be documented in writing. • To pass the course, 5 sufficient experiment preparations, 5 sufficient experiment executions and the passed asynchronous online test are required.

		• Es sind 5 Experimente zu absolvieren sowie vorab ein Online-Test zu Matlab-Kenntnissen und Grundkenntnissen in digitaler Kommunikation. Die Einzelheiten sind in den Kursunterlagen beschrieben. • Jedes Experiment muss zu Hause schriftlich vorbereitet werden. Die Vorbereitung wird zu Beginn eines jeden Experiments überprüft und bewertet (ausreichend/nicht ausreichend). • Die Ergebnisse jedes Experiments sind während der Durchführung des Experiments auf den Versuchsrechnern festzuhalten (Programmieraufgaben) und werden am Ende des Experiments kontrolliert (ausreichend/nicht ausreichend). Die gemessenen Ergebnisse sind schriftlich zu dokumentieren. • Zum Bestehen des Kurses sind 5 ausreichende Versuchsvorbereitungen, 5 ausreichende Versuchsdurchführungen sowie der bestandene asynchrone Online-Test erforderlich.
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german english
16	Bibliography	• Skriptum zum Praktikum • Skriptum zur Vorlesung Digitale Übertragung bzw. Digital Communications • übliche Standardlehrwerke zur Thematik (Proakis, Haykin usw.)

Planning & Control - Core modules

1	Module name 92519	Robotics 1	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Knut Graichen Dr.-Ing. Andreas Völz
5	Contents	This lecture introduces the fundamentals of robotics with a focus on manipulator control. The course covers the following topics: - Modeling: coordinate systems and transformations, parameterization of rotation matrices, forward and inverse kinematics, Jacobians and singularities - Trajectory planning: polynomial and trapezoidal trajectories, trajectories with intermediate points, trajectories in task space - Linear control: actuator dynamics, decentralized motion control, basics of task space and force control
6	Learning objectives and skills	After successful completion of the module, students will be able to - mathematically describe and analyze the kinematics of robotic manipulators. - plan trajectories for robot motions. - design and implement linear methods for robot motion and force control.
7	Prerequisites	- Basis knowledge of advanced mathematics - Basic knowledge of control theory
8	Integration in curriculum	semester: 6
9	Module compatibility	Planning & Control - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	M. Spong, S. Hutchinson und M. Vidyasagar: Robot Modeling and Control. Wiley, 2005. B. Siciliano, L. Sciavicco, G. Oriolo und L. Villani: Robotics Modelling, Planning and Control. Springer, 2009. J. Craig: Introduction to Robotics: Mechanics and Control. Pearson, 2018.

1	Module name 92529	Nonlinear Control Systems Nonlinear control systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Knut Graichen
5	Contents	Many control problems are nonlinear by nature. Classical control methods are based on linear approximations or a linearization of these systems in the neighborhood of setpoints to be controlled. In contrast to linear control theory, this module focuses on advanced nonlinear methods for the analysis and control of nonlinear systems by exploiting structural properties. In summary, the course covers the following topics: • Examples of nonlinear physical systems and nonlinear phenomena • Introduction to computer algebra software • Analysis of nonlinear systems • Stability of nonlinear systems (Lyapunov stability) • Lyapunov-based control design (Backstepping) • Reachability/controllability and observability of nonlinear systems • Exact linearization via feedback • Differential flatness of nonlinear systems • Flatness-based feedforward and feedback control of nonlinear systems
6	Learning objectives and skills	After successful completion of the module, students will be able to • describe and analyze nonlinear systems • determine the input/output behavior of nonlinear systems • design nonlinear state feedback controllers via exact input-output and input-state linearization • apply the concept of differential flatness for the feedforward feedback control of nonlinear systems • use computer algebra software for the analysis and control design of nonlinear systems
7	Prerequisites	Basic knowledge of advanced mathematics Linear control theory (state space methods), e.g. "Regelungstechnik B"
8	Integration in curriculum	semester: 6
9	Module compatibility	Planning & Control - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h

		Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• H.K. Khalil. Nonlinear Systems, Prentice Hall, 2002 • S. Sastry. Nonlinear Systems, Springer, 1999 • A. Isidori. Nonlinear Control Systems, Springer, 3. Auflage, 1995 • J. Adamy. Nichtlineare Regelungen, Springer, 2009 • J.-J. Slotine, W. Li. Applied Nonlinear Control, Prentice Hall, 1991 • M. Vidyasagar. Nonlinear Systems Analysis, Prentice Hall, 2. Auflage, 1993 • M. Krstic, I. Kanellakopoulos, P. Kokotovic. Nonlinear and Adaptive Control Design, John Wiley & Sons, 1995

1	Module name 92528	Numerical Optimization and Model Predictive Control Numerical optimization and model predictive control	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Knut Graichen
5	Contents	Many problems in economy and industry require an optimal solution under consideration of specific criteria and constraints. From a mathematical point of view, this requires the numerical solution of a parametric optimization problem or a dynamic optimization problem. The latter formulation accounts for the dynamics of the underlying process and is particularly relevant in the context of optimal control and model predictive control (MPC). In summary, the course covers the following topics: • Introduction to and examples of static and dynamic optimization problems • Unconstrained numerical optimization (optimality conditions, numerical methods) • Constrained numerical optimization (linear/quadratic/nonlinear problems, optimality conditions, numerical methods) • Dynamical optimization / optimal control problems (calculus of variations, optimality conditions, PMP, numerical methods) • Nonlinear model predictive control (formulations, stability, real-time solution)
6	Learning objectives and skills	After successful completion of the module, students will be able to • differentiate the problem classes of parametric and dynamic optimization • formulate and analyze practical optimization problems • derive and solve the optimality conditions for unconstrained and constrained optimization problems using state-of-the-art software tools • classify the different formulations and stability criteria for nonlinear model predictive control • design a model predictive controller for a given control task and analyze the performance and stability properties in closed loop • realize and implement a real-time MPC for highly dynamical nonlinear systems with sampling times in the (sub)millisecond range using modern state-of-the-art (N)MPC software
7	Prerequisites	Basic knowledge of advanced mathematics (especially linear algebra) Basic knowledge of dynamical systems in time domain description (e.g. Regelungstechnik B)
8	Integration in curriculum	semester: 6

9	Module compatibility	Planning & Control - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	S. Boyd, L. Vandenberghe. Convex Optimization. Cambridge University Press, 2004 J. Nocedal, S.J. Wright. Numerical Optimization. New York: Springer, 2006 M. Papageorgiou, M. Leibold, M. Buss. Optimierung. Berlin: Springer, 2012 C.T. Kelley. Iterative Methods for Optimization. Society for Industrial und Applied Mathematics (SIAM), 1999 D.P. Bertsekas. Nonlinear Programming. Belmont. Athena Scientific, 1999 E. Camacho, C. Alba. Model Predictive Control. 2. Auflage, Springer, 2004 L. Grüne, J. Pannek. Nonlinear Model Predictive Control: Theory and Algorithms, Springer, 2011

1	Module name 43405	Introduction to Deep Learning Introduction to deep learning	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Introduction to Deep Learning (2 SWS) Übung: Supplements for Introduction to Deep Learning (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Vasileios Belagiannis Marc Hölle	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis
5	Contents	The students will learn the basics in deep learning, including classical neural network models and recent architectures. The students will acquire knowledge on processing different types of data with deep neural networks. In the exercises, the students will implement some of the standard models for classification or regression tasks and acquire knowledge on machine learning applications. The lecture topics include: • Learning from data, machine learning and deep learning • Machine learning principles • Artificial neural networks • Convolutional neural networks • Back-propagation • Network optimization • Initialisation, regularisation • Deep network architectures • Generative models • Auto-encoders • Sequential models • Deep learning applications
6	Learning objectives and skills	The students will learn: • Machine learning theory • Artificial neural networks • Deep neural networks • Modern architectures • Model and parameter learning
7	Prerequisites	Basic knowledge of higher mathematics and programming
8	Integration in curriculum	semester: 5;6

9	Module compatibility	Planning & Control - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242	
10	Method of examination	Written examination (90 minutes) Written exam of 90min duration	
11	Grading procedure	Written examination (100%)	
12	Module frequency	Only in winter semester	
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h	
14	Module duration	1 semester	
15	Teaching and examination language	english	
16	Bibliography		• Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning. • Rojas, R. (2013). Neural networks: a systematic introduction. • Friedman, J., Hastie, T., & Tibshirani, R. (2001). The elements of statistical learning.

Planning & Control - Specialization modules

1	Module name 92535	Robotics 2	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Robotics 2 (4 SWS)	5 ECTS
3	Lecturers	Dr.-Ing. Andreas Völz	

4	Module coordinator	Dr.-Ing. Andreas Völz
5	Contents	This lecture introduces advanced methods of robotics with a focus on manipulator control. The course covers the following topics: • Dynamics: Euler-Lagrange formulation, recursive Newton-Euler algorithm, extensions of the dynamical model • Nonlinear control: Lyapunov stability, gravity compensation, inverse dynamics, adaptive control, task space control • Motion planning: Time-optimal trajectory generation, collision checking, configuration space, local path planning, global path planning • Mobile robots: Basics of control and planning
6	Learning objectives and skills	The students are able to • derive the dynamical model of a robotic manipulator using the Euler-Lagrange equations and the recursive Newton-Euler algorithm • design and implement nonlinear methods for robot motion and force control and analyze their stability using Lyapunov theory • plan collision-free motions for robots in known environments using local and global planning algorithms
7	Prerequisites	Recommended prior knowledge: Basics of advanced mathematics, control theory and robotics
8	Integration in curriculum	semester: 6
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• M. Spong, S. Hutchinson und M. Vidyasagar: Robot Modeling and Control. Wiley, 2005. • B. Siciliano, L. Sciavicco, G. Oriolo und L. Villani: Robotics Modelling, Planning and Control. Springer, 2009. • J. Craig: Introduction to Robotics: Mechanics and Control. Pearson, 2018.

	• S. LaValle: Planning algorithms, Cambridge University Press, 2006.

1	Module name 97060	Regelungstechnik B (Zustandsraummethoden) Control engineering B (State-space methods)	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Regelungstechnik B (Zustandsraummethoden) (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr.-Ing. Knut Graichen	

4	Module coordinator	Prof. Dr.-Ing. Knut Graichen
5	Contents	Das Modul vermittelt die Grundlagen zur Beschreibung und Untersuchung von linearen dynamischen Systemen mit mehreren Ein- und Ausgangsgrößen im Zustandsraum sowie den zustandsraumbasierten Regler- und Beobachterentwurf. Die Inhalte sind: • Motivation der Zustandsraumbetrachtung dynamischer Systeme in der Regelungstechnik • Zustandsraumdarstellung dynamischer Systeme und deren Vereinfachung durch Linearisierung • Analyse linearer und zeitinvarianter Systeme: Stabilität, Steuerbarkeit, Beobachtbarkeit, Zusammenhang mit Ein-/Ausgangsbetrachtung • Auslegung von linearen Zustandsreglern für lineare Eingrößensysteme • Erweiterte Regelkreisstrukturen, insbesondere Vorsteuerung und Störgrößenkompensation • Entwurf von Zustands- und Störgrößenbeobachtern und Kombination mit Zustandsreglern (Separationsprinzip)
6	Learning objectives and skills	Die Studierenden können • die Vorzüge der Zustandsraumbetrachtung im Vergleich zur Ein-/Ausgangsbetrachtung darlegen. • für dynamische Systeme die Zustandsgleichungen aufstellen und durch Linearisierung vereinfachen. • für LZI-Systeme die Zustandsgleichungen in Normalformen transformieren. • Stabilität, Steuer- und Beobachtbarkeit von Zustandssystemen definieren und LZI-Systeme daraufhin untersuchen. • ausführen, wie diese Eigenschaften mit den Eigenwerten und Nullstellen von LZI-Zustandssystemen zusammenhängen. • den Aufbau einer Zwei-Freiheitsgrade-Zustandsregelung angeben und die Zweckbestimmung ihrer einzelnen Komponenten erläutern. • realisierbare Vorsteuerungen zur Einstellung des Sollverhaltens entwerfen. • Zielstellung und Aufbau eines Zustandsbeobachters erläutern. • diesen zu einem Störbeobachter erweitern und Störaufschaltungen zur Kompensation von Dauerstörungen konzipieren. • beobachterbasierte Zustandsregelungen durch Eigenwertvorgabe entwerfen.

		die Vorlesungsinhalte auf verwandte Problemstellungen übertragen und sich die Zustandsraummethoden der Regelungstechnik selbständig weiter erschließen.
7	Prerequisites	Empfohlene Vorkenntnisse: Vektor- und Matrizenrechnung sowie Grundlagen der Regelungstechnik (klassische Frequenzbereichsmethoden; kann auch parallel gehört werden, siehe Regelungstechnik A)
8	Integration in curriculum	semester: 1
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Die Summe der in den freiwilligen Testaten erzielten Punktzahl wird zu max. 10% auf die Klausurpunktzahl angerechnet. Hiermit ist eine Verbesserung der Klausurbewertung um bis zu 0,7 Notenpunkte möglich. Die Anrechnung erfolgt nur, wenn Sie die Prüfung an sich mit der Mindestnote 4,0 bestanden haben. Der Bonus kann nur einmal im Prüfungszeitraum der Vorlesung angerechnet werden, entweder zum Haupttermin nach Vorlesungsende oder zum Nachholtermin im Folgesemester, wenn der Haupttermin nicht wahrgenommen wurde.
11	Grading procedure	Written examination (100%) Die Summe der in den freiwilligen Testaten erzielten Punktzahl wird zu max. 10% auf die Klausurpunktzahl angerechnet. Hiermit ist eine Verbesserung der Klausurbewertung um bis zu 0,7 Notenpunkte möglich. Die Anrechnung erfolgt nur, wenn Sie die Prüfung an sich mit der Mindestnote 4,0 bestanden haben. Der Bonus kann nur einmal im Prüfungszeitraum der Vorlesung angerechnet werden, entweder zum Haupttermin nach Vorlesungsende oder zum Nachholtermin im Folgesemester, wenn der Haupttermin nicht wahrgenommen wurde.
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	- C.T. Chen. Control System Design, Pond Woods Press, 1987 O. Föllinger. Regelungstechnik: Einführung in die Methoden und ihre Anwendung. 8. Auflage, Hüthig, 1994 H. Geering. Regelungstechnik, 6. Auflage, Springer, 2004 T. Kailath. Linear Systems, Prentice Hall, 1980 G. Ludyk. Theoretische Regelungstechnik 1, Springer, 1995 - D.G. Luenberger. Introduction to Dynamic Systems, John Wiley & Sons, 1979 J. Lunze. Regelungstechnik 1, 12. Auflage, Springer, 2020 J. Lunze. Regelungstechnik 2, 10. Auflage, Springer, 2020

	• L. Padulo, M.A. Arbib. System Theory, W.B. Saunders Company, 1974 • W.J. Rugh. Linear System Theory 2, Prentice Hall, 1996

1	Module name 97360	Digitale Regelung Digital control	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr.-Ing. Andreas Michalka
5	Contents	Es werden Aufbau u. mathematische Beschreibung digitaler Regelkreise für LZI-Systeme sowie Verfahren zu deren Analyse und Synthese betrachtet: • quasikontinuierliche Beschreibung und Regelung der Strecke unter Berücksichtigung der DA- bzw. AD-Umsetzer • zeitdiskrete Beschreibung der Regelstrecke als Zustandsdifferenzengleichung oder z-Übertragungsfunktion • Analyse von Abtastsystemen, Stabilität, Steuer- und Beobachtbarkeit • Regelungssynthese: Steuerungsentwurf, Zustandsregelung und Beobachterentwurf, Störungen im Regelkreis, Berücksichtigung von Totzeiten, Intersampling-Verhalten".
6	Learning objectives and skills	Die Studierenden • erläutern Aufbau und Bedeutung digitaler Regelkreise. • leiten mathematische Beschreibungen des Abtastsystems in Form von Zustandsdifferenzengleichungen oder z-Übertragungsfunktionen her. • analysieren Abtastsysteme und konzipieren digitale Regelungssysteme auf Basis quasikontinuierlicher sowie zeitdiskreter Vorgehensweisen. • entwerfen Steuerungen, Regelungen und Beobachter und bewerten die erzielten Ergebnisse. • diskutieren abtastregelungsspezifische Effekte und bewerten Ergebnisse im Vergleich mit dem kontinuierlichen Systemverhalten.
7	Prerequisites	Es wird empfohlen folgende Module zu absolvieren, bevor dieses Modul belegt wird: • Regelungstechnik A (Grundlagen) (RT A) oder Einführung in die Regelungstechnik (ERT) • Regelungstechnik B (Zustandsraummethoden) (RT B)
8	Integration in curriculum	semester: 1
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Schriftliche Prüfung (Klausur, mit 90 Minuten Dauer).
11	Grading procedure	Written examination (100%)

12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 94961	Schätzverfahren in der Regelungstechnik Estimation Methods for Control Systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Thomas Moor
5	Contents	• Überbestimmte lineare Gleichungssysteme zur Parameter- und Zustandsschätzung • Least Squares Schätzer via quadratischer Ergänzung • Least Squares Schätzer via Projektionssatz • Linear Least Mean Squares Schätzer stochastischer Größen • Kalman-Filter • Extended Kalman-Filter
6	Learning objectives and skills	Die Studierenden • erkennen, ob und wie eine regelungstechnische Problemstellung in dem vorgestellten Rahmen der Schätzverfahren formuliert und gelöst werden kann • erläutern die herangezogenen mathematischen Grundlagen, insbesondere aus der linearen Algebra • können die vermittelten Ansätze im Kontext von einfachen Beispielen anwenden und die jeweils erzielten Ergebnisse kritisch bewerten.
7	Prerequisites	Grundlagen der Analysis und Algebra, wie sie z.B. in den Veranstaltungen "Mathematik für Ingenieure" angeboten werden; Grundlagen der Regelungstechnik, z.B. durch Belegung der Module: • Regelungstechnik A (Grundlagen) • Regelungstechnik B (Zustandsraummethoden)
8	Integration in curriculum	semester: 5
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	Kailath et al.; Linear Estimation, Prentice Hall, 2000.

1	Module name 92430	Ereignisdiskrete Systeme	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Thomas Moor
5	Contents	Formale Sprachen als Modelle ereignisdiskreter Dynamik • reguläre Ausdrücke, endliche Automaten, Nerode-Äquivalenz • natürliche Projektion, synchrone Komposition, Konfliktfreiheit. Entwurf ereignisdiskreter Regler: • Sicherheitsspezifikation, Konfliktfreiheit • supremale steuerbare Teilsprache, Fixpunktiterationen • Normalität, Regelung unter eingeschränkter Beobachtbarkeit. Anwendungsstudie: • Modellbildung eines einfachen technischen Prozesses • Spezifikation/Entwurf/Simulation am Anwendungsbeispiel
6	Learning objectives and skills	Teilnehmer dieser Veranstaltung • erklären, illustrieren und validieren die vorgestellten Grundlagen formaler Sprachen, • entwickeln einfache Ergänzungen zu den vorgestellten Grundlagen formaler Sprachen, • erklären und illustrieren die vorgestellten Entwurfsverfahren, • überprüfen die vorgestellten Entwurfsverfahren hinsichtlich einzelner Lösungseigenschaften, • entwickeln ereignisdiskrete Modelle einfacher technischer Prozesse, einschließlich formaler Spezifikationen, • wählen im Kontext einfacher technischer Prozesse geeignete Entwurfsverfahren aus und wenden diese kritisch an, • bewerten ihre Regelkreise im Simulationsexperiment.
7	Prerequisites	Es wird empfohlen, eines der folgenden Module zu absolvieren, bevor dieses Modul belegt wird: • Regelungstechnik A (Grundlagen) (RT A) • Einführung in die Regelungstechnik (ERT)
8	Integration in curriculum	semester: 1
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Schriftliche Prüfung (Klausur, mit 90 Minuten Dauer).
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h

14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	Cassandras, C.G., Lafortune, S.: Introduction to Discrete Event Systems, Kluwer, 1999

1	Module name 96430	Statistical Signal Processing Statistical signal processing	5 ECTS
2	Courses / lectures	Übung: Übung zur Statistischen Signalverarbeitung (1 SWS) Vorlesung: Statistische Signalverarbeitung (3 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr.-Ing. Sebastian Schlecht Baoqi Bai	

4	Module coordinator	Prof. Dr.-Ing. Sebastian Schlecht
5	Contents	The course concentrates on fundamental methods of statistical signal processing and their applications. The main topics are: - Discrete-time stochastic processes in the time and frequency domain: Random variables (RVs), probability distributions and densities, expectations of random variables, transformation of RVs, vectors of normally distributed RVs, time-discrete random processes: probability distribution and densities, expectation, stationarity, cyclostationarity, ergodicity, correlation functions and correlation matrices, spectral representations, principal component analysis (PCA), Karhunen-Loève transform (KLT). - Estimation theory: estimation criteria, prediction, classical and Bayesian parameter estimation (including MMSE, Maximum Likelihood, and Maximum A Posteriori estimation), Cramer-Rao bound - Linear signal models: Parametric models (cepstral decomposition, Paley-Wiener theorem, spectral flatness), non-parametric models (all-pole, all-zero and pole-zero models, lattice structures, Yule-Walker equations, PARCOR coefficients, cepstral representation) - Signal estimation: Supervised estimation, problem classes, orthogonality principle, MMSE estimation, linear MMSE estimation for normally distributed random processes, optimum FIR filtering, optimum linear filtering for stationary processes, prediction and smoothing, Kalman filters, optimum multichannel filtering (Wiener filter, LCMV, MVDR, GSC) - Adaptive filtering: Gradient methods, LMS, NLMS, APA and RLS algorithms and their convergence behavior
6	Learning objectives and skills	The students: - analyze the statistical properties of random variables, random vectors, and stochastic processes by probability density functions and expectations as well as correlation functions and matrices and their frequency-domain representations - know the Gaussian distribution and its role to describe the properties of random variables, vectors and processes - understand the differences between classical and Bayesian estimation, derive and analyze MMSE and ML estimators for specific estimation problems, especially for signal estimation

		- analyze and evaluate optimum linear MMSE estimators (single- and multichannel Wiener filter and Kalman filter) for direct and inverse supervised estimation problems - evaluate adaptive filters for the identification of optimum linear estimators.
7	Prerequisites	Courses on signals and systems as well as digital signal processing strongly recommended
8	Integration in curriculum	semester: 5
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Written exam of 90min duration.
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	A. Papoulis, S. Pillai: Probability, Random Variables and Stochastic Processes; McGraw-Hill, 2002 D. Manolakis, V. Ingle, S. Kogon: Statistical and Adaptive Signal Processing; Artech House, 2005

1	Module name 48440	Machine Learning in Signal Processing Machine learning in signal processing	5 ECTS
2	Courses / lectures	Übung: Übung zu Maschinelles Lernen in der Signalverarbeitung (2 SWS) Vorlesung: Maschinelles Lernen in der Signalverarbeitung (2 SWS)	- 5 ECTS
3	Lecturers	Michele De Vita Marc Hölle Prof. Dr. Vasileios Belagiannis	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis	
5	Contents	This course is an introduction into machine learning and artificial intelligence. The special emphasis is on applications to modern signal processing problems. The course is focused on design principles of machine learning algorithms. The lectures start with a short introduction, where the nomenclature is defined. After this, probabilistic graphical models are introduced and the use of latent variables is discussed, concluding with a discussion of hidden Markov models and Markov fields. The second part of the course is about deep learning and covers the use of deep neural networks for machine learning tasks. In the last part of the lecture, the use of deep neural networks for speech processing tasks is introduced. The course is based on the materials and video footage from Dr. Roland Maas. He is an outstanding machine learning expert and a former member of the Chair of Multimedia Communications and Signal Processing.	
6	Learning objectives and skills	After attending the lecture, students will be able to • understand regression and classification problems • apply PDF estimation algorithms • understand Gaussian mixture models and expectation-maximization • apply principal component analysis and independent component analysis • assess different estimation algorithms • explain the application of machine learning to system identification • apply hidden Markov models • understand different artificial neural network architectures • explain deep learning principles • apply artificial neural networks • devise learning strategies for deep neural networks • assess the application of deep neural networks for speech processing tasks.	
7	Prerequisites	None	
8	Integration in curriculum	semester: 5	
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242	

		Sensing & Perception - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Written exam of 90min duration
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Literature: • C. M. Bishop: Pattern Recognition and Machine Learning, http://www.research.microsoft.com/en-us/um/people/cmbishop/PRML • S. Theodoridis and K. Koutroumbas: Pattern Recognition • M. Nielsen: Neural Networks and Deep Learning.

1	Module name 44120	Pattern Analysis Pattern analysis	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	PD Dr.-Ing. Christian Riess
5	Contents	This lecture is the sequel to the lecture "<i>Pattern Recognition</i>". As such, it covers topics from the chapters 8-14 from the book "<i>Pattern Recognition and Machine Learning</i>" by Christopher Bishop. These topics include various aspects of Bayesian modeling, including (but not limited to) • probabilistic graphical models • mixture modeling • variational inference • sampling methods • manifold learning • Markov random fields • hidden Markov models • tree-based methods • ensembling
6	Learning objectives and skills	The students • explain the discussed methods for classification, prediction, and analysis of patterns, • compare and analyze methods for manifold learning and select a suited method for a given set of features and a given problem, • compare and analyze methods for probability density estimation and select a suited method for a given set of features and a given problem, • apply non-parametric probability density estimation to pattern analysis problems, • apply dimensionality reduction techniques to high-dimensional feature spaces, • explain statistic modeling of feature sets and sequences of features, • explain statistic modeling of statistical dependencies
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable (60 minutes) Die Prüfung ist eine schriftliche Klausur mit Multiple Choice mit einer Dauer von 60 Minuten.

		--- The form of examination is a written exam with multiple choice with a duration of 60 minutes.
11	Grading procedure	Variable (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Begleitende Literatur / Accompanying literature: • C. Bishop: Pattern Recognition and Machine Learning, Springer Verlag, Heidelberg, 2006 • T. Hastie, R. Tibshirani und J. Friedman: The Elements of Statistical Learning, 2nd Edition, Springer Verlag, 2009 • A. Criminisi and J. Shotton: Decision Forests for Computer Vision and Medical Image Analysis, Springer, 2013

1	Module name 44130	Pattern Recognition Pattern recognition	5 ECTS
2	Courses / lectures	Übung: PR Exercise (1 SWS) Vorlesung: Pattern Recognition (3 SWS)	1,25 ECTS 3,75 ECTS
3	Lecturers	Linda-Sophie Schneider Dr.-Ing. Siming Bayer Prof. Dr.-Ing. Andreas Maier	

4	Module coordinator	Prof. Dr.-Ing. Andreas Maier
5	Contents	Mathematical foundations of machine learning based on the following classification methods: • Bayesian classifier • Logistic Regression • Naive Bayes classifier • Discriminant Analysis • norms and norm dependent linear regression • Rosenblatt's Perceptron • unconstraint and constraint optimization • Support Vector Machines (SVM) • kernel methods • Expectation Maximization (EM) Algorithm and Gaussian Mixture Models (GMMs) • Independent Component Analysis (ICA) • Model Assessment • AdaBoost Mathematische Grundlagen der maschinellen Klassifikation am Beispiel folgender Klassifikatoren: • Bayes-Klassifikator • Logistische Regression • Naiver Bayes-Klassifikator • Diskriminanzanalyse • Normen und normabhängige Regression • Rosenblatts Perzeptron • Optimierung ohne und mit Nebenbedingungen • Support Vector Maschines (SVM) • Kernelmethoden • Expectation Maximization (EM)-Algorithmus und Gaußsche Mischverteilungen (GMMs) • Analyse durch unabhängige Komponenten • Modellbewertung • AdaBoost
6	Learning objectives and skills	Die Studierenden • verstehen die Struktur von Systemen zur maschinellen Klassifikation einfacher Muster • erläutern die mathematischen Grundlagen ausgewählter maschineller Klassifikatoren • wenden Klassifikatoren zur Lösung konkreter Klassifikationsproblem an

		• beurteilen unterschiedliche Klassifikatoren in Bezug auf ihre Eignung • verstehen in der Programmiersprache Python geschriebene Lösungen von Klassifikationsproblemen und Implementierungen von Klassifikatoren Students • understand the structure of machine learning systems for simple patterns • explain the mathematical foundations of selected machine learning techniques • apply classification techniques in order to solve given classification tasks • evaluate various classifiers with respect to their suitability to solve the given problem • understand solutions of classification problems and implementations of classifiers written in the programming language Python
7	Prerequisites	• Well grounded in probability calculus, linear algebra/matrix calculus • The attendance of our bachelor course 'Introduction to Pattern Recognition' is not required but certainly helpful. • Gute Kenntnisse in Wahrscheinlichkeitsrechnung und Linearer Algebra/Matrizenrechnung • Der Besuch der Bachelor-Vorlesung 'Introduction to Pattern Recognition' ist zwar keine Voraussetzung, aber sicherlich von Vorteil.
8	Integration in curriculum	semester: 1
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german or english english
16	Bibliography	• Richard O. Duda, Peter E. Hart, David G. Stock: Pattern Classification, 2nd edition, John Wiley&Sons, New York, 2001 • Trevor Hastie, Robert Tibshirani, Jerome Friedman: The Elements of Statistical Learning - Data Mining, Inference, and Prediction, 2nd edition, Springer, New York, 2009 • Christopher M. Bishop: Pattern Recognition and Machine Learning, Springer, New York, 2006

1	Module name 93185	Reinforcement Learning Reinforcement learning	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr.-Ing. Christopher Mutschler	
5	Contents	The lecture aims at teachin Reinforcement Learning (RL) and will cover the following topics: • Introduction to Reinforcement Learning (Agent-Environment-Interface, Markov Decision Processes) • Dynamic Programming (Bellman Equations, Value Iteration, Policy Iteration) • Model-Free Prediction • Model-Free Control • Value Function Approximation (Linear VFA and DQNs) • Policy-based Reinforcement Learning (Monte-Carlo Policy Gradient, Advantage Estimators, TRPO, PPO) • Model-based RL • Offline RL • Explainable RL • Exploration-Exploitation • Simulation to Reality Transfer • Research frontiers & hot topics, Sim2Real & Real-World Applications	
6	Learning objectives and skills	The students will learn to • understand the basic principle behind sequestration decision making problems and how to translate them into a formal model • compare and analyze methods different agents to search for policies • implement the presented methods in PyTorch, • discuss the social impact of applications that automate decision making	
7	Prerequisites	Es handelt sich hier um eine Spezialisierungsvorlesung, eine erfolgreiche Absolvierung der Vorlesungen IntroPR" und/oder Pattern Recognition"/"Pattern Analysis" wird empfohlen. Konzepte, die in IntroPR" vermittelt werden, werden hier als Grundwissen vorausgesetzt.	
8	Integration in curriculum	semester: 1	
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242	
10	Method of examination	Variable (90 minutes) • The examination will include a written exam of 90 minutes at the end of the semester	

		The exam will cover the content of the lecture as well as that of the exercises (the exam will hence contain a mixture of theoretical questions and practical coding tasks) Please note that the exam will only take place in summer terms.
11	Grading procedure	Variable (100%) Written Exam (100 %)
12	Module frequency	Only in summer semester The lecture and exam will only be able during summer terms.
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	- Richard S. Sutton and Andrew G. Barto. 2018. Reinforcement Learning: An Introduction. A Bradford Book, Cambridge, MA, USA. - Bellman, R.E. 1957. Dynamic Programming. Princeton University Press, Princeton, NJ. Republished 2003: Dover, ISBN 0-486-42809-5. - Csaba Szepesvari and Ronald Brachman and Thomas Dietterich. 2010. Algorithms for Reinforcement Learning. Morgan and Claypool Publishers. - Warren B. Powell. 2011. Approximate Dynamic Programming. Wiley. - Maxim Lapan. 2020. Deep Reinforcement Learning Hands-On: Apply modern RL methods to practical problems of chatbots, robotics, discrete optimization, web automation, and more, 2nd Edition. Packt Publishing. - Dimitri P. Bertsekas. 2017. Dynamic Programming and Optimal Control. Athena Scientific. - Miguel Morales. 2020. grokking Deep Reinforcement Learning. Manning. - Laura Graesser and Keng Wah Loon. 2019. Foundations of Deep Reinforcement Learning: Theory and Practice in Python. Addison-Wesley Data & Analytics.

1	Module name 94951	Grundlagen der Robotik Fundamentals of robotics	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Jörg Franke
5	Contents	Das Modul Grundlagen der Robotik richtet sich insbesondere an die Studierenden der Informatik, des Maschinenbaus, der Mechatronik, der Medizintechnik sowie des Wirtschaftsingenieurwesens. Es werden zunächst die Grundlagen der modernen Robotik erläutert und anschließend fachspezifische Grundlagen zur Konzeption, Implementierung und Realisierung von Robotersystemen vermittelt. Hierbei liegt der Fokus neben klassischen Industrierobotern auch auf neuen Robotertechnologien für den Service-, Pflege- und Medizinbereich. Es werden weiterhin die Grundlagen des Robot Operating System (ROS) vermittelt und es wird durch praktische Übungen die Arbeit und Roboterprogrammierung mit ROS erlernt. Das Modul umfasst hierfür die nachfolgenden Themenschwerpunkte: • Bauformen, Begriffe, Definitionen, Historie, rechtliche Grundlagen und Roboterethik • Roboteranwendungen in Industrie, Service, Pflege und Medizin • Sensorik und Aktorik für Robotersysteme • Kinematik und Dynamik verschiedener Roboterbauformen • Steuerung, Regelung und Bahnplanung • Varianten der Roboterprogrammierung • Planung und Simulation von Robotersystemen • Robot Operating System (ROS) • Computer Vision (OpenCV)
6	Learning objectives and skills	Ziel ist, den Studierenden einen fundierten Überblick über aktuelle Roboterapplikationen zu vermitteln sowie die grundlegenden Bauformen, Begrifflichkeiten und gesetzlichen Rahmenbedingungen vorzustellen. Darauf aufbauen werden die notwendigen technischen Grundlagen moderner Robotersysteme sowie die Programmierung eines Roboters mit ROS erlernt. Die Studierenden sind in der Lage: • Roboter hinsichtlich ihrer Eigenschaften zu klassifizieren, das für eine vorgegebene Anwendung optimale Robotersystem auszuwählen und hierbei ethische und arbeitsschutzrechtliche Aspekte zu berücksichtigen. • Robotersysteme auszulegen, zu entwickeln und die erforderlichen Bewegungsabläufe zu planen, • die für verschiedene Roboterapplikationen notwendige Sensorik und Aktorik auszuwählen,

		• Robotersysteme durch den Einsatz von Planungs- und Simulationswerkzeugen zu validieren • sowie Roboter mit Hilfe des Robot Operating Systems zu programmieren und zu steuern.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (120 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 92880	Robotics Frameworks Robotics frameworks	5 ECTS
2	Courses / lectures	Übung: Exercise Robotics Frameworks (0 SWS) Vorlesung: Robotics Frameworks (4 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Nina Merz Dr.-Ing. Sebastian Reitelshöfer	

4	Module coordinator	Prof. Dr.-Ing. Jörg Franke
5	Contents	• Basic concepts of robotics • Basic concepts of the Robot Operating System • Simulation of robots in virtual environments • Computer vision and machine learning in the context of robotics • Path and gripping grasp planning • Localization, mapping and navigation of mobile robots • Flow control with state machines for complex robot tasks • Introduction to relevant software frameworks for specific tasks (Robot Operating System, Gazebo, OpenCV, Tensorflow) • Solving a complex practical task as a team
6	Learning objectives and skills	In this module, students independently implement advanced tasks in robotics and related topics such as simulation, computer vision and machine learning using concrete examples. In doing so, the students deal with various established software frameworks and learn how to use them. Students are taught the following technical and methodological competences: After completing the module, students will be able to • Classify important terms of robotics • Understand the challenges of modern robotics in relation to complex tasks and develop approaches to solve them. • Analyse and practically apply complex issues in robotics (robotics frameworks, simulation tools and frameworks for image processing and artificial intelligence) • Explain and apply methods of robot motion control and planning • Explain the self-localisation of mobile robots and examine it using examples The students additionally acquire and train the following personal and social competences within the framework of the team task: After completing the module, the students can • Independently solve preparatory tasks • Organize their working time • Work together with other students in a group in a goal-oriented manner • Assess their own strengths and use them in a targeted way in the team performance

7	Prerequisites	Recommended Prerequisites : Basic knowledge of programming languages C++ and Python, additional information can be found on StudOn
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 95280	Verteilte Systeme Distributed systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	PD Dr.-Ing. Tobias Distler
5	Contents	Verteilte Systeme bestehen aus mehreren Rechnern, die über ein Netzwerk miteinander verbunden sind und einen gemeinsamen Dienst erbringen. Obwohl die beteiligten Rechner hierfür in weiten Teilen unabhängig voneinander agieren, erscheinen sie ihren Nutzern gegenüber in der Gesamtheit dabei trotzdem als ein einheitliches System. Die Einsatzmöglichkeiten für verteilte Systeme erstrecken sich über ein weites Spektrum an Szenarien: Von der Zusammenschaltung kleinster Rechenknoten zur Sammlung von Daten im Rahmen von Sensornetzwerken über Steuerungssysteme für Kraftfahrzeuge und Industrieanlagen bis hin zu weltumspannenden, Internet-gestützten Infrastrukturen mit Komponenten in Datenzentren auf verschiedenen Kontinenten. Ziel dieses Moduls ist es, die sich durch die speziellen Eigenschaften verteilter Systeme ergebenden Problemstellungen zu verdeutlichen und Ansätze zu vermitteln, mit deren Hilfe sie gelöst werden können; Beispiele hierfür sind etwa die Interaktion zwischen heterogenen Systemkomponenten, der Umgang mit erhöhten Netzwerklatenzen sowie die Wahrung konsistenter Zustände über Rechengrenzen hinweg. Gleichzeitig zeigt das Modul auf, dass die Verteiltheit eines Systems nicht nur Herausforderungen mit sich bringt, sondern auf der anderen Seite auch Chancen eröffnet. Dies gilt insbesondere in Bezug auf die im Vergleich zu nicht verteilten Systemen erzielbare höhere Widerstandsfähigkeit eines Gesamtsystems gegenüber Fehlern wie den Ausfällen ganzer Rechner oder sogar kompletter Datenzentren. Ausgehend von den einfachsten, aus nur einem Client und einem Server bestehenden verteilten Systemen, beschäftigt sich die Vorlesung danach mit der deutlich komplexeren Replikation der Server-Seite und behandelt anschließend die Verteilung eines Systems über mehrere, mitunter weit voneinander entfernte geografische Standorte. In allen Abschnitten umfasst die Betrachtung des jeweiligen Themas eine Auswahl aus Grundlagen, im Praxiseinsatz befindlicher Ansätze und Techniken sowie für den aktuellen Stand der Forschung repräsentativer Konzepte. Im Rahmen der Übungen wird zunächst ein plattformunabhängiges Fernaufrufsystem schrittweise entwickelt und parallel dazu getestet. Als Vorlage und Orientierungshilfe dient dabei das in der Praxis weit verbreitete Java RMI. In den weiteren Übungsaufgaben stehen anschließend klassische Problemstellungen von verteilten Systemen

		wie fehlertolerante Replikation und verteilte Synchronisation im Mittelpunkt.
6	Learning objectives and skills	Studierende, die das Modul erfolgreich abgeschlossen haben: • beschreiben charakteristische Merkmale und Eigenschaften verteilter Systeme sowie grundlegende Probleme im Zusammenhang mit ihrer Realisierung. • untersuchen die Unterschiede zwischen lokalen Methodenaufrufen und Fernmethodenaufrufen. • vergleichen Ansätze zur Konvertierung von Nachrichten zwischen verschiedenen Datenrepräsentationen. • konzipieren eine eigene auf Java RMI basierende Anwendung. • entwickeln ein eigenes Fernaufrufsystem nach dem Vorbild von Java RMI. • gestalten ein Modul zur Unterstützung verschiedener Fernaufrufsemantiken (Maybe, Last-of-Many) für das eigene Fernaufrufsystem. • beurteilen auf Basis eigener Experimente mit Fehlerinjektionen die Auswirkungen von Störeinflüssen auf verschiedene Fernaufrufsemantiken. • klassifizieren Mechanismen zur Bereitstellung von Fehlertoleranz, insbesondere verschiedene Arten der Replikation (aktiv vs. passiv). • vergleichen verschiedene Konsistenzgarantien georeplizierter Systeme. • illustrieren das Problem einer fehlenden gemeinsamen Zeitbasis in verteilten Systemen. • erforschen logische Uhren als Mittel zur Reihenfolgebestimmung und Methoden zur Synchronisation physikalischer Uhren. • unterscheiden grundlegende Zustellungs- und Ordnungsgarantien beim Multicast von Nachrichten. • gestalten ein Protokoll für den zuverlässigen und totalgeordneten Versand von Nachrichten in einer Gruppe von Knoten. • entwickeln einen Dienst zur Verwaltung verteilter Sperrobjekte auf Basis von Lamport-Locks. • bewerten die Qualität einer Publikation aus der Fachliteratur. • erschließen sich typische Probleme (Nebenläufigkeit, Konsistenz) und Fehlerquellen bei der Programmierung verteilter Anwendungen. • können in Kleingruppen kooperativ arbeiten. • können ihre Entwurfs- und Implementierungsentscheidungen kompakt präsentieren und argumentativ vertreten. • können offen und konstruktiv mit Schwachpunkten und Irrwegen umgehen. • reflektieren ihre Entscheidungen kritisch und leiten Alternativen ab.
7	Prerequisites	Gute Programmierkenntnisse in Java

8	Integration in curriculum	semester: 5
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination Das Modul wird bestanden bei erfolgreicher Bearbeitung aller 6 Übungsaufgaben (Bewertung jeweils mit "ausreichend") und dem Bestehen einer 30-minütigen mündlichen Prüfung.
11	Grading procedure	Written examination (100%) Die Modulnote ergibt sich zu 100% aus der Bewertung der mündlichen Prüfung.
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 42800	Advanced Topics in Deep Learning Advanced topics in deep learning	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis
5	Contents	The students will learn advanced deep learning topics, including recent network architectures, generative models, self-supervision, interpretability and explainability. In the exercises, the students will implement advanced models and techniques for classification or regression tasks. The lecture topics include: • Geometric deep learning • Attention and transformers • Unsupervised and self-supervised learning • Generative models • Interpretability • Explainability • Efficient Inference • Uncertainty estimation • Transfer learning and domain adaptation • Few-shot learning
6	Learning objectives and skills	The students will learn: • State-of-the-art topics in Deep Learning • Recent Neural network architectures • Generative modelling • Lifelong learning approaches • Robustness and reliability in Deep Learning.
7	Prerequisites	Basic knowledge of machine learning, deep learning, and programming.
8	Integration in curriculum	semester: 1
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Written exam of 90 min duration
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester

15	Teaching and examination language	english
16	Bibliography	• Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning. • Deisenroth, M. P., Faisal, A. A., & Ong, C. S. (2020). Mathematics for machine learning. Cambridge University Press. • Molnar, C. (2020). Interpretable machine learning. Lulu. com.

1	Module name 47575	Gait analysis and simulation+	5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Prof. Dr. Anne Koelewijn
5	Contents	The aim of this course is to teach methods of gait analysis and simulation. The lectures start with an introduction to relevant anatomic terms and definitions, followed by an introduction to the motions performed when walking or running. Different sensors and laboratory equipment are introduced, which are used to record gait/human movement. We will discuss different processing methods that can be used to determine relevant kinetic and kinematic parameters related to gait, such as joint angles, joint moments, and muscle forces. The second half of the lectures will focus on gait simulations. First, we discuss simulation methods, dynamic models and optimization techniques used to create gait simulations. Second, neural control of gait is discussed, as well as how simulations can be created to investigate this neural control. This lecture addresses the following topics: • Measurement systems for gait analysis • Methods to calculate joint kinetics and kinematics from experimental data • Muscle biology specific to force generation, and modelling of muscles • Methods to calculate muscle activation and force from experimental data • Energetics of walking • Multibody dynamics • Trajectory optimization for gait simulations Gait simulations based on neural control models
6	Learning objectives and skills	Knowledge: • The students learn what a normal walking and running gait cycle looks like • The students learn about the human body and commonly used anatomical and engineering terms that are important to describe locomotion. • The students learn about commonly used measurement and processing techniques to measure and calculate biomechanical parameters related to gait • The students learn how human gait simulations can be created. • The students learn about the control of human gait. Understanding: • The students understand the advantages and disadvantages of different data processing methods, models, and gait simulation methods.

		- The students understand when a simulation and when an experiment is appropriate to answer a research question Application - The students are able to develop an approach to answer a research question related to gait - The students are able to perform a gait analysis experiment and process with state-of-the-art methods - The students are able to implement numerical simulation methods in MATLAB or Python - The students are able to use the open source software OpenSim and SCONE Analyse - The students are able to analyse gait kinetics and kinematics and identify abnormalities
7	Prerequisites	No compulsory prerequisites. Background knowledge on multibody dynamics, simulation, and optimization is recommended
8	Integration in curriculum	semester: 1
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Tutorial achievement Variable Written examination
11	Grading procedure	Tutorial achievement (pass/fail) Variable (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	?? semester (no information for Module duration available)
15	Teaching and examination language	
16	Bibliography	

Planning & Control - Seminar & laboratory

1	Module name 878210	Lab course machine learning in signal processing	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis
5	Contents	This is an advanced level lab course in machine learning. Imagine a car driving on an autobahn in an automatic mode. Among other things, the car needs to steer itself to keep driving in it's own lane. To accomplish this, the central problem is to detect the road-lane markings. These are the white solid or dashed lines that are drawn on each side of the lane. The standard modern approach to solve this type of problems is to take a large dataset of labeled examples and train a deep neural network model to accomplish the task. This is how car and pedestrian detection algorithms are developed. The difficulty with the road-lane markings is that there is no labeled dataset of them and creating such dataset would cost millions of dollars. In this lab course we will solve this problem using transfer learning and mathematical modeling: • Create cartoon-like artificial images of a road with known locations for the lane markings. • Train deep neural network on these artificial images with heavy data augmentations that mimic real-world images. • Create a dataset of unlabeled real-life videos by downloading and organizing examples from youtube. • Create a machine learning pipeline for working with these videos efficiently. • Apply the neural network that has been trained on artificial data to the real world videos. • Analyze the quality of results produced by the network. • Use mathematical modeling to correct the outputs of the network. • Retrain the network on the dataset composed of the corrected outputs. • Measure and analyze the quality of the results. The software will be written in Python using JupyterLab development framework. Access to modern GPU server will be provided. The best students will have the opportunity to contribute to the creation of state-of-the-art lane detection system for self-driving cars during or after the course.
6	Learning objectives and skills	Students are able to: • Independently design machine learning pipelines to solve complex problems in artificial intelligence. • Choose appropriate algorithms for the problem at hand.

		• Use standard packages for machine learning in Python: numpy, cvxpy, scikit-learn, pywavelets, pytorch. • Debug and calibrate machine learning algorithms. Develop modification to the standard algorithms as appropriate to the problem at hand. • Explain the theoretical aspects of deep learning.
7	Prerequisites	Knowledge of Python programming language is required. Basic theoretical knowledge in machine learning is assumed: consider taking the Machine Learning in Signal Processing (MLSIP) course in the same semester.
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Planning & Control - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement To pass the lab course, the programming tasks of each of the 5 session must be successfully completed.
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 15 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 47656	Legged Locomotion of Robots (LLR) Legged locomotion of robots (LLR)	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Anne Koelewijn
5	Contents	Legged robotics help researchers understand human and animal locomotion. Furthermore, legged robots have many different applications, for example to aid in dangerous environments and in rehabilitation. Active prosthetics and exoskeletons improve gait of people with a disability, like a spinal cord injury or an amputation. The goal of this seminar is to become familiar with different algorithms and analysis methods that are used for legged robotics. Important concepts here are the energetics and the stability. Robots should be energy efficient, in the case of an exoskeleton to not lose battery power for a day. Obviously, stability is important to avoid falls. Each student will perform a literature review of a specific concept related to robot locomotion. The concepts can be chosen from a list, or the student can propose their own topic. Students can choose to perform an extra assignment to receive an additional 2.5 ECTS. The assignment will require the student to implement the chosen concept in simulation or in practice.
6	Learning objectives and skills	- Familiarize with different concepts that are used in control and analysis of robot locomotion - Understand the theoretical background of concepts of robot locomotion - Differentiate between different types of robots - Understand the stability and energetics in robot locomotion
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Planning & Control - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Seminar achievement
11	Grading procedure	Seminar achievement (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

Sensing & Perception - Core modules

1	Module name 96316	Radar, RFID and Wireless Sensor Systems (RWS) Radar, RFID and wireless sensor systems (RWS)	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Martin Vossiek
5	Contents	Radar, RFID and wireless sensor and wireless locating systems are essential for automotive advanced driver-assistance systems (ADAS), autonomous driving and flying, robotics, industrial automation, logistics and novel human machine interfaces. Further key areas include medical electronics, building technology and cyber-physical systems. The module "Radar, RFID and Wireless Sensors" is an introduction into functional principles, building blocks, hardware and signal processing concepts and applications of modern radar, RFID, wireless sensor and real time locating systems. Covered applications include automotive radar, road and air traffic control systems, as well as robotics, industrial automation and medical technology. RWS is an identical replacement of the former module "Drahtlose Sensoren, Radar- und RFID-Systeme DSR.
6	Learning objectives and skills	The students • learn about the setup, function and application of wireless sensors, Radar and RFID-systems • can analyze, discuss and implement basic components and system structures, signal theory, data processing and use cases • can determine the underlying physical limitations and sources of errors • are able to analyze and create system specifications and can compare and rate the usability of wireless esnsors, Radar and RFID-systems • can create and define independently applications and system designs of RWSs
7	Prerequisites	None
8	Integration in curriculum	semester: 6
9	Module compatibility	Sensing & Perception - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written (90 minutes)
11	Grading procedure	Written (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h

14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Sensors for Ranging and Imaging", Graham Brooker, Scitech Publishing Inc., 2009 Radar mit realer und synthetischer Apertur", H. Klausing, W. Holpp, Oldenbourg, 1999 Praxiswissen Radar und Radarsignalverarbeitung" Albrecht K. Ludloff, 2008 "RFID at ultra and super high frequencies: theory and application Dominique Paret, John Wiley & Sons, 2009. RFID-Handbuch: Grundlagen und praktische Anwendungen von Transpondern, kontaktlosen Chipkarten und NFC", Klaus Finkenzeller, Carl Hanser Verlag, 6. Auflage 2012.

1	Module name 96430	Statistical Signal Processing Statistical signal processing	5 ECTS
2	Courses / lectures	Übung: Übung zur Statistischen Signalverarbeitung (1 SWS) Vorlesung: Statistische Signalverarbeitung (3 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr.-Ing. Sebastian Schlecht Baoqi Bai	

4	Module coordinator	Prof. Dr.-Ing. Sebastian Schlecht
5	Contents	The course concentrates on fundamental methods of statistical signal processing and their applications. The main topics are: - Discrete-time stochastic processes in the time and frequency domain: Random variables (RVs), probability distributions and densities, expectations of random variables, transformation of RVs, vectors of normally distributed RVs, time-discrete random processes: probability distribution and densities, expectation, stationarity, cyclostationarity, ergodicity, correlation functions and correlation matrices, spectral representations, principal component analysis (PCA), Karhunen-Loève transform (KLT). - Estimation theory: estimation criteria, prediction, classical and Bayesian parameter estimation (including MMSE, Maximum Likelihood, and Maximum A Posteriori estimation), Cramer-Rao bound - Linear signal models: Parametric models (cepstral decomposition, Paley-Wiener theorem, spectral flatness), non-parametric models (all-pole, all-zero and pole-zero models, lattice structures, Yule-Walker equations, PARCOR coefficients, cepstral representation) - Signal estimation: Supervised estimation, problem classes, orthogonality principle, MMSE estimation, linear MMSE estimation for normally distributed random processes, optimum FIR filtering, optimum linear filtering for stationary processes, prediction and smoothing, Kalman filters, optimum multichannel filtering (Wiener filter, LCMV, MVDR, GSC) - Adaptive filtering: Gradient methods, LMS, NLMS, APA and RLS algorithms and their convergence behavior
6	Learning objectives and skills	The students: - analyze the statistical properties of random variables, random vectors, and stochastic processes by probability density functions and expectations as well as correlation functions and matrices and their frequency-domain representations - know the Gaussian distribution and its role to describe the properties of random variables, vectors and processes - understand the differences between classical and Bayesian estimation, derive and analyze MMSE and ML estimators for specific estimation problems, especially for signal estimation

		- analyze and evaluate optimum linear MMSE estimators (single- and multichannel Wiener filter and Kalman filter) for direct and inverse supervised estimation problems - evaluate adaptive filters for the identification of optimum linear estimators.
7	Prerequisites	Courses on signals and systems as well as digital signal processing strongly recommended
8	Integration in curriculum	semester: 5
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Written exam of 90min duration.
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	A. Papoulis, S. Pillai: Probability, Random Variables and Stochastic Processes; McGraw-Hill, 2002 D. Manolakis, V. Ingle, S. Kogon: Statistical and Adaptive Signal Processing; Artech House, 2005

1	Module name 92343	Image, Video, and Multidimensional Signal Processing Image, video, and multidimensional signal processing	5 ECTS
2	Courses / lectures	Vorlesung: Image, Video, and Multidimensional Signal Processing (2 SWS) Übung: Supplements Image, Video, and Multidimensional Signal Processing	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Andre Kaup Katja Kossira	

4	Module coordinator	Prof. Dr.-Ing. Andre Kaup
5	Contents	Punktoperationen Histogrammausgleich, Gamma-Korrektur Binäroperationen Morphologische Filter, Erosion, Dilatation, Opening, Closing Farbräume Trichromat, RGB- Farbraum, HSV-Farbraum Mehrdimensionale Signale und Systeme Theorie mehrdimensionaler Signale und Systeme, Impulsantwort, lineare Bildfilterung, Leistungsspektrum, Wiener Filter Interpolation von Bildsignalen Bilineare Interpolation, Bicubische Interpolation, Spline Interpolation Merkmalsdetektion in Bildern Bildmerkmale, Kantendetektion, Hough Transformation, Harris Ecken Detektor, Texturmerkmale, Grauwertematrix Skalierungsraumdarstellung LoG, DoG, SIFT, SURF Bildabgleich Projektive Abbildungen, Blockabgleich, Optischer Fluss, Merkmalsbasierter Abgleich mittels SIFT und SURF, RANSAC Bildsegmentierung Amplituden Schwellenwertermittlung, K-Means Clustering, Bayes Klassifikation, Regionen-basierte Segmentierung, kombinierte Segmentierung und Bewegungsschätzung, zeitliche Segmentierung von Videos Bildverarbeitung im Transformationsbereich Unitäre Transformation, Karhunen-Loeve Transformation, separable Transformationen, Haar und Hadamard Transformation, DFT, DCT Content: Point operations Histogram equalization, gamma correction

		Binary operations Morphological filters, erosion, dilation, opening, closing Color spaces Trichromacy, red-green-blue color spaces, color representation using hue, saturation and value of intensity Multidimensional signals and systems Theory of multidimensional signals and systems, impulse response, linear image filtering, power spectrum, Wiener filtering Interpolation of image signals Bi-linear interpolation, bi-cubic interpolation, spline interpolation Image feature detection Image features, edge detection, Hough transform, Harris corner detector, texture features, co-occurrence matrix Scale space representation Laplacian of Gaussian, difference of Gaussian, scale invariant feature transform, speeded-up robust feature transform Image matching Projective transforms, block matching, optical flow, feature-based matching using SIFT and SURF, random sample consensus algorithm Image segmentation Amplitude thresholding, k-means clustering, Bayes classification, region-based segmentation, combined segmentation and motion estimation, temporal segmentation of video Transform domain image processing Unitary transform, Karhunen-Loeve transform, separable transform, Haar and Hadamard transform, DFT, DCT
6	Learning objectives and skills	The students • understand point operations for image data and gamma correction • test the effects of rank order and median filters for image data • evaluate and differentiate between different color spaces for image data • explain the principle of two-dimensional linear filtering for image signals • calculate and evaluate the two-dimensional discrete Fourier transform of an image signal • determine enlarged discrete image signals by bi-linear and spline interpolation • verify image data for selected texture, edge and motion features • analyze image and video data for features in different scale spaces • explain and evaluate methods for the matching of image data

		- segment image data by implementing basic classification and clustering methods - understand the principle of transformations on image data and apply them exemplarily
7	Prerequisites	None
8	Integration in curriculum	semester: 5
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	- J.-R. Ohm: Multimedia Content Analysis, Springer, 2016 J. W. Woods: Multidimensional Signal, Image, and Video Processing and Coding, Academic Press, 2nd edition, 2012

1	Module name 48440	Machine Learning in Signal Processing Machine learning in signal processing	5 ECTS
2	Courses / lectures	Übung: Übung zu Maschinelles Lernen in der Signalverarbeitung (2 SWS) Vorlesung: Maschinelles Lernen in der Signalverarbeitung (2 SWS)	- 5 ECTS
3	Lecturers	Michele De Vita Marc Hölle Prof. Dr. Vasileios Belagiannis	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis	
5	Contents	This course is an introduction into machine learning and artificial intelligence. The special emphasis is on applications to modern signal processing problems. The course is focused on design principles of machine learning algorithms. The lectures start with a short introduction, where the nomenclature is defined. After this, probabilistic graphical models are introduced and the use of latent variables is discussed, concluding with a discussion of hidden Markov models and Markov fields. The second part of the course is about deep learning and covers the use of deep neural networks for machine learning tasks. In the last part of the lecture, the use of deep neural networks for speech processing tasks is introduced. The course is based on the materials and video footage from Dr. Roland Maas. He is an outstanding machine learning expert and a former member of the Chair of Multimedia Communications and Signal Processing.	
6	Learning objectives and skills	After attending the lecture, students will be able to • understand regression and classification problems • apply PDF estimation algorithms • understand Gaussian mixture models and expectation-maximization • apply principal component analysis and independent component analysis • assess different estimation algorithms • explain the application of machine learning to system identification • apply hidden Markov models • understand different artificial neural network architectures • explain deep learning principles • apply artificial neural networks • devise learning strategies for deep neural networks • assess the application of deep neural networks for speech processing tasks.	
7	Prerequisites	None	
8	Integration in curriculum	semester: 5	
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242	

		Sensing & Perception - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Written exam of 90min duration
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Literature: • C. M. Bishop: Pattern Recognition and Machine Learning, http://www.research.microsoft.com/en-us/um/people/cmbishop/PRML • S. Theodoridis and K. Koutroumbas: Pattern Recognition • M. Nielsen: Neural Networks and Deep Learning.

Sensing & Perception - Specialization module

1	Module name 96310	Image and Video Compression Image and video compression	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Andre Kaup
5	Contents	Multi-Dimensional Sampling - Sampling theorem revisited, 2D sampling, spatiotemporal sampling, motion in 3D sampling Entropy and Lossless Coding - Entropy and information, variable length codes, Huffman coding, unary coding, Golomb coding, arithmetic coding Statistical Dependency - Joint entropy and statistical dependency, run-length coding, fax compression standards Quantization - Rate distortion theory, scalar quantization, Lloyd-Max quantization, entropy coded scalar quantization, embedded quantization, adaptive quantization, vector quantization Predictive Coding - Lossless predictive coding, optimum 2D linear prediction, JPEG-LS lossless compression standard, differential pulse code modulation (DPCM) Transform Coding - Principle of transform coding, orthonormal transforms, Karhunen-Loève transform, discrete cosine transform, bit allocation, compression artifacts Subband Coding - Principle of subband coding, perfect reconstruction property, discrete wavelet transform, bit allocation for subband coding Visual Perception and Color - Anatomy of the human eye, sensitivity of the human eye, color spaces, color sampling formats Image Coding Standards - JPEG and JPEG2000 Interframe Coding - Interframe prediction, motion compensated prediction, motion estimation, motion compensated hybrid coding Video Coding Standards - H.261, H.263, MPEG-1, MPEG-2 / H.262, H.264 / MPEG-4 AVC, H.265 / MPEG-H HEVC
6	Learning objectives and skills	The students - visualize multi-dimensional sampling and the influence of motion within the video signal - differentiate and evaluate different methods for lossless image and video coding

		• understand and analyze mutual entropy and statistical dependencies in image and video data • determine scalar and vector quantization for different optimization criteria (minimum mean square error, entropy coding, embedded quantization) • determine and evaluate optimal one-dimensional and two-dimensional linear predictor • apply prediction and quantization for a common DPCM system • understand the principle and effects of transform and subband coding for image data including optimal bit allocation • describe the principles of the human visual system for brightness and color • analyze block diagrams and the functioning of hybrid coders and decoders for video signals • know the prevailing international standards of ITU and MPEG for image and video compression.
7	Prerequisites	Lectures on Signal and Systems and Communication Systems strongly recommended
8	Integration in curriculum	semester: 2
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written or oral (90 minutes) Written exam of 90 min duration
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	J.-R. Ohm: Multimedia Communications Technology, Springer, 2004

1	Module name 93173	Computational Visual Perception Computational visual perception	7,5 ECTS
2	Courses / lectures	Vorlesung: Computational Visual Perception (4 SWS) Projektseminar: Tutorials to Computational Visual Perception (2 SWS)	2,5 ECTS 5 ECTS
3	Lecturers	Prof. Dr. Tim Weyrich Prof. Dr. Andreas Kist PD Dr. habil. Patrick Krauß Prof. Dr. Bernhard Egger	

4	Module coordinator	Prof. Dr. Bernhard Egger Prof. Dr. Andreas Kist Prof. Dr.-Ing. Andreas Maier	
5	Contents	How do humans perceive the visual world? How can we build computational models to mimic this human perception? And how can we validate those computational models? This course is designed as an introduction to enable you to build computational models for human visual perception. It will therefore provide an introduction into the human visual system building on the course on cognitive neuroscience for AI developers. You will learn how the human eye and brain process visual input and what we currently know about the ventral visual stream. We will look at computational models for all different levels of visual processing and discuss how well they measure behavioral data. This lecture is designed to be at the intersection of Computer Science (Computer Vision and Graphics) and Cognitive Neuroscience. After an initial introductory phase, you will in small teams (1-3 students) perform a project to build prototypes for computational models for visual processing, reproduce recent scientific results or experiment with existing models. In addition to the project phase we will read and discuss recent research papers studying potential computational models and investigate how we can evaluate computational models. Please sign up via studon	
6	Learning objectives and skills	By the end of this course, students will be able to • Describe the basic processing steps of visual input in the human brain • Build a computational model for a known processing step • Read recent papers in the discipline and design a follow-up experiment • Choose/design and conduct a small research project • Choose adequate methods to evaluate a computational model • Work in and manage projects	
7	Prerequisites	None	
8	Integration in curriculum	semester: 4	
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242	

		Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Tutorial achievement Written (60 minutes) There are 3 exercises, and participants must pass 2 of them. There is no separate grade for the exercises (only pass/fail).
11	Grading procedure	Tutorial achievement (pass/fail) Written (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 90 h Independent study: 135 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 44400	Radar Signal Processing Radar signal processing	5 ECTS
2	Courses / lectures	Vorlesung: Radar Signal Processing (2 SWS) Übung: Radar Signal Processing Exercises (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Gerhard Krieger	

4	Module coordinator	Prof. Dr.-Ing. Gerhard Krieger
5	Contents	Radar is a key technology for a growing number of sensing tasks that range from the detection, location and tracking of moving objects to high-resolution imaging of surfaces, sub-surfaces and 3-D volumes. While the traditional radar applications focused on aerospace security, weather services and traffic surveillance, radar is now becoming a central contactless sensor technology for the automotive sector, medical diagnostics, gesture control, civil engineering, as well as large scale environmental and climate change monitoring, to name only a few. Associated with the new applications is an increasing demand for advanced signal processing techniques to extract the relevant information from the microwave echoes acquired by single- and multi-aperture radar systems in complex environments. This lecture will give an overview of a variety of one-, two-, and three-dimensional radar signal and image processing algorithms and their application for different sensing tasks. The theoretical derivations are complemented by computer examples and simulations that form an integral part of both the lecture and the exercises. The lecture covers the following topics: • Introduction (radar principles & applications, signal & noise models, interference, Doppler shift) • Basics of Signal Processing with Python (Jupyter Notebooks) • Data Acquisition (I/Q demodulation, complex signal representation, sampling, quantization) • Range Processing (radar waveforms, pulse compression, ambiguity function, sidelobe reduction) • Doppler Processing (MTI, clutter suppression, range-Doppler ambiguities, spectral estimation) • Detection Theory (target models, Neyman-Pearson criterion, CFAR detector, CRBs) • Multi-Channel Processing (spatial filtering, interference suppression, adaptive beamforming) • Synthetic Aperture Radar (basics of coherent imaging, SAR data model, time-domain processing) • SAR Focusing Algorithms (range-Doppler, chirp scaling, motion compensation, autofocus) • SAR Image Analysis (image statistics, speckle filtering, segmentation, classification) • Radar Polarimetry (wave representations, scattering models, polarimetric decomposition) • Interferometry (interferometric processing chain, statistical performance models, applications)

		• Tomography (principles of 3-D imaging, tomographic processing, remote sensing applications) • Space-Time Adaptive Processing (GMTI, optimum processor, pre- & post-Doppler STAP) • Advanced Topics (bi- & multistatic radar, MIMO radar, compressive sensing)
6	Learning objectives and skills	Fachkompetenz Verstehen • understand the basic principles and applications of radar systems • understand the statistical properties of SAR images and their combinations • understand current developments associated with bi- and multistatic SAR, MIMO radar, etc. Anwenden • implement signal processing algorithms for radar detection and parameter estimation • use performance metrics for the evaluation of radar systems and signal processing algorithms • focus coherent radar raw data into high-resolution SAR images • apply space-time adaptive processing techniques for ground moving target indication Analysieren • select and apply spectral processing techniques for clutter and interference suppression • simulate the performance of radar systems in complex environments Erschaffen • combine multiple complex-valued SAR images into higher-level information products
7	Prerequisites	Keine formalen Voraussetzungen, aber grundlegende Kenntnisse erforderlich in • Signal- und Systemtheorie, • Wahrscheinlichkeitstheorie • Lineare Algebra. Von Vorteil wären zudem Vorkenntnisse auf einem Teil der folgenden Gebiete: • statistische Signalverarbeitung • Hochfrequenztechnik • Radarsysteme • Nachrichtentechnische Systeme.
8	Integration in curriculum	semester: 1
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral

		Prüfungsform: mündlich (30 Minuten)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• The handouts distributed at the beginning of each lecture cover the entire material and are fully sufficient for exam preparation. • ◦ M. Richards, Fundamentals of Radar Signal Processing, McGraw-Hill, 2nd ed., 2014 ◦ I. Cumming, F. Wong, Digital Processing of Synthetic Aperture Radar Data, Artech House, 2004 ◦ J. Curlander, R. Donough, Synthetic Aperture Radar Systems & Signal Processing, Wiley, 1991 ◦ F. Ulaby, D. Long, Microwave Radar and Radiometric Remote Sensing, Michigan Press, 2014 ◦ C. Oliver, S. Quegan, Understanding Synthetic Aperture Images, Scitech, 2004 ◦ H. Van Trees, Optimum Array Processing, Wiley Interscience, 2002 ◦ J. Guerci, Space-Time Adaptive Processing for Radar, Artech House, 2nd ed., 2015 ◦ R. Hanssen, Radar Interferometry, Kluwer Academic Publishers, 2001 ◦ J. Li, P. Stoica, MIMO Radar Signal Processing, Wiley, 2008

1	Module name 621649	Advanced Optical Communication Systems Advanced optical communication systems	5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Prof. Dr.-Ing. Bernhard Schmauß
5	Contents	Multiplex Techniques: electrical / optical time division multiplexing, wavelength division multiplexing • Dispersion Management: dispersion and bitrate, dispersion compensation, dispersion in WDM systems • Noise and Power Management: power budget, OSNR management, OSNR calculation • Management of Nonlinearities: self & cross phase modulation (SPM / XPM), four wave mixing (FWM), Raman scattering, solitons • Spectral Efficiency: definition, increase of spectral efficiency • Modulation Formats: intensity modulation, multilevel transmission, CS-RZ, SSB Transmission, DPSK, DQPSK, Coherent Transmission • Optical Regeneration: 2R-Regeneration by nonlinearities, distributed regeneration, 3R-Regeneration
6	Learning objectives and skills	Students • gain detailed Knowledge on concepts and structure of various optical transmission systems. • are able to analyze, to compare and evaluate the quality of optical data signals with respect to different system concepts. • are able to develop and to optimize link designs of optical transmission systems. • are able to systematically improve the performance of optical links taking into account state of the art and leading edge scientific results.
7	Prerequisites	Recommended Prerequisites: • Fundamentals in signals and systems. • Basic knowledge of fiber optics and optoelectronic components recommended.
8	Integration in curriculum	semester: 1
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes) Examination: oral exam (30 Minutes)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h

		Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Agrawal, G.P.: Fiber-Optic Communication Systems, John Wiley & Sons, 1997 Agrawal, G.P.: Nonlinear Fiber Optics, John Wiley & Sons, 3. Auflage, 2001. Kaminow, I, Koch, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002. Kaminow, I, Li, T., Willner, A.: Optical Fiber Telecommunications VA, Academic Press, 2008. Lecture notes.

1	Module name 67145	Waveguides, optical fibres and photonic crystal fibres	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Waveguides, optical fibres and photonic crystal fibres (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Nicolas Joly Prof. Dr.-Ing. Bernhard Schmauß	

4	Module coordinator	Prof. Dr. Nicolas Joly Prof. Dr.-Ing. Bernhard Schmauß
5	Contents	1) Fundamental of waveguides (Guidance mechanism, modes and dispersion, geometrical and electromagnetic approach) 2) Photonic crystal fibres (PCF) 3) Nonlinear optics in PCF (soliton, supercontinuum generation, nonlinear optics in gases in hollow-core PCF) 4) Optical communication systems (system outline, waveguide components, transmission effects, performance limitations) 5) Optical fibre sensors: fibre sensing principles, waveguide-based sensing component, distributed sensing, sensor, network, sensor signal processing)
6	Learning objectives and skills	The students will be able - to identify a particular type of microstructure fibre for a dedicated experiment - to calculate the mode content supported by a specific fibre and model the modal properties - to evaluate the potential limitations of an optical fibre due to nonlinear effects - to choose the appropriate fibre (dispersion and nonlinearity) to generate quiet or very broad supercontinuum spectral using a photonic crystal fibre - to choose the appropriate type of fibre-based sensor according to the signal to probe - to understand the performance limitation of the telecommunications systems
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester

15	Teaching and examination language	english
16	Bibliography	

1	Module name 42801	Perception in Robotics Perception in robotics	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis
5	Contents	The students will learn robotic perception topics, including camera models, filtering, transformations, low-level features, point-cloud processing, recognition, pose estimation, localization, mapping, depth, and motion estimation. In the exercises, the students will implement techniques for different perception modules. The lecture topics include: • Sensor models • Camera calibration • Feature detection and matching. • Edges, lines, circles. • Transformations. • Multiple views. • Recognition. • Pose estimation. • Localization and mapping. • Depth estimation. • Point-cloud processing.
6	Learning objectives and skills	no learning objectives and skills description available!
7	Prerequisites	Basic knowledge of image and signal processing
8	Integration in curriculum	semester: 1
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Written examination of 90 min duration
11	Grading procedure	Written examination (100%) A grade bonus of 0.3 is awarded for regular participation in the exercise assignments. The grade bonus can only be counted towards the overall grade only if the examination is passed. A grade improvement from 5.0 to 4.0 is not possible.
12	Module frequency	Only in summer semester

13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• Szeliski, Richard. Computer vision: algorithms and applications. Springer Nature, 2022. • Thrun, Sebastian, Wolfram Burgard, and Dieter Fox. "Probabilistic robotics.", MIT Press. • Hartley, Richard, and Andrew Zisserman. Multiple view geometry in computer vision. Cambridge University Press, 2003

1	Module name 44455	Speech and Language Processing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Andreas Maier
5	Contents	Nach Behandlung der grundlegenden Mechanismen menschlicher Spracherzeugung und Sprachwahrnehmung gibt die Vorlesung eine detaillierte Einführung in (vornehmlich) statistisch orientierte Methoden der maschinellen Erkennung gesprochener Sprache. Schwerpunktthemen sind Merkmalsextraktion, Vektorquantisierung, akustische Sprachmodellierung mit Hilfe von Markovmodellen, linguistische Sprachmodellierung mit Hilfe stochastischer Grammatiken, prosodische Information sowie Suchalgorithmen zur Beschleunigung des Dekodiervorgangs. After focussing on of the basic mechanisms of human speech generation and speech perception the lecture gives a detailed introduction to (mainly) statistically oriented methods of automatic recognition of spoken language. Main topics are feature extraction, vector quantization, acoustic speech modeling with the help of Markov models, linguistic speech modeling with the help of stochastic grammars, prosodic information as well as search algorithms to speed up the decoding process.
6	Learning objectives and skills	Die Studierenden • verstehen die Grundlagen der menschlichen Sprachproduktion und die akustischen Eigenschaften unterschiedlicher Phonemklassen • erklären den allgemeinen Aufbau eines Mustererkennungssystems • verstehen Abtastung, das Abtasttheorem und Quantisierung in Bezug auf Sprachsignale • verstehen die Fourier-Transformation und mathematische Modelle der Sprachproduktion • verstehen harte und weiche Vektorquantisierungsmethoden • verstehen unüberwachtes Lernen (EM-Algorithmus) • verstehen Hidden Markov-Modelle (HMMs) • erklären stochastische Sprachmodelle The students • understand the principles of human speech production and acoustic properties of the different phoneme classes • explain the general pipeline of a pattern recognition system • understand sampling, the sampling theorem, and quantization w.r.t. speech signals

		• understand Fourier transformation and mathematical models of speech production • understand hard and soft vector quantization methods • understand unsupervised learning (EM-algorithm) • understand Hidden Markov Models (HMMs) • explain stochastic language models
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (60 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• Niemann H.: Klassifikation von Mustern; Springer, Berlin 1983 • Niemann H.: Pattern Analysis and Understanding; Springer, Berlin 1990 • Schukat-Talamazzini E.G.: Automatische Spracherkennung; Vieweg, Wiesbaden 1995 • ◦ Rabiner L.R., Juang B.H.: Fundamentals of Speech Recognition; Prentice Hall, New Jersey 1993

1	Module name 498723	Transformationen in der Signalverarbeitung Transforms in signal processing	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	PD Dr.-Ing. Jürgen Seiler
5	Contents	Das Modul "Transformationen in der Signalverarbeitung" behandelt mehrere verschiedene Transformationen, die im Rahmen der Signalverarbeitung Verwendung finden. Dabei werden zuerst die grundlegenden Konzepte von Transformationen diskutiert und die Vorteile die Transformationen mit sich bringen erläutert. Im Anschluss daran werden die grundlegenden Eigenschaften von Integraltransformationen betrachtet und die Laplace- und die Fourier-Transformation im Detail untersucht. Um auch zeitlich veränderliche Signale gut transformieren zu können werden danach die Kurzzeit-Fourier-Transformation und die Gabor-Transformation eingeführt. Im Anschluss daran erfolgt eine Betrachtung der Auswirkung der Abtastung auf transformierte Signale, bevor die z-Transformation als Transformation für diskrete Signale behandelt wird. Abschließend erfolgt die Betrachtung weiterer Transformationen für diskrete Signale wie der Diskreten Fourier-Transformation oder linearer Block-Transformationen. The module "Transforms in Signal Processing" covers several different transforms which are used in the field of signal processing. For this, first the basic concepts of transforms are discussed and the advantages which are offered by the different transforms are presented. Subsequent to this, fundamental properties of integral transforms are considered and the Laplace- and the Fourier-Transform are examined in detail. To be able to transform time-varying signals, the Short-Time Fourier-Transform and the Gabor-Transform are introduced, afterwards. Subsequent to this, the impact of sampling on transformed signals is analyzed before the z-Transform as a transform for discrete signals is covered. Finally, further transforms for discrete signals like the Discrete Fourier-Transform or Linear-Block Transforms are discussed.
6	Learning objectives and skills	Die Studierenden können nach Besuch der Vorlesung • Anwendungsmöglichkeiten von Transformationen bestimmen • Integraltransformationen gegenüberstellen und untersuchen • die Existenz von Transformationen hinterfragen • die Eindeutigkeit von Transformationen überprüfen • Sätze und Eigenschaften von Transformationen entwickeln • zu Transformationen zugehörige inverse Transformationen einschätzen • die Zusammenhänge zwischen verschiedenen Transformationen einschätzen • auf Zusammenhänge zwischen Ausgangssignalen und transformierten Signalen folgern • Symmetriebeziehungen von Transformationen ausarbeiten

		• Zusammenhänge zwischen kontinuierlichen und diskreten Signalen ausarbeiten Educational Objectives and Competences: After attending the lecture, students will be able to • determine applications of transforms • contrast and examine integral transforms • question the existence of transforms • evaluate the uniqueness of transforms • develop theorems and properties of transforms • evaluate to transforms corresponding inverse transforms • evaluate the relationships between different transforms • assess the relationship between original signal and transformed signals • devise the symmetry properties of transforms • devise the relationship between continuous and discrete signals
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral Mündliche Prüfung von 30 min Dauer.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	K. Krüger, Transformationen - Grundlagen und Anwendungen in der Nachrichtentechnik, Vieweg Verlag, Braunschweig B. Girod, R. Rabenstein, A. Stenger, Einführung in die Systemtheorie, B. G. Teubner Verlag, Stuttgart

1	Module name 267499	Linear and non-linear fibre optics	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Bernhard Schmauß
5	Contents	Optical data transmission systems are the enabler for our modern communication networks. Since the first systems have been installed, the transmission capacity as well as the transmission distance has been increased dramatically. The migration from point-to-point transmission systems to complex optical networks is still in progress. The fast evolution of optical transmission technology is stimulated by innovations in the field of the system key components. The lectures concentrate on the physical effects and properties of key components like semiconductor lasers, optical modulators, optical fibers, optical amplifiers and detector diodes. Especially also the nonlinear effects of the transmission fiber are discussed. The main focus is on the effects and characteristics which are important to achieve a certain system performance. The influence of component parameters on system performance is presented in examples related to installed systems and systems that are actually in development. The exercises partly use a numerical simulation tool to analyze the component influence on system performance.
6	Learning objectives and skills	Students • Understand structure and operation of components of optical communication systems • Rate the optical properties of components and evaluate the influence of operational parameters on system performance • Are able to analyze the influence of linear and nonlinear fiber effects on optical signals and system performance • Can make use of system simulation tools to engineer optical links
7	Prerequisites	Recommended prior knowledge: • Semiconductor physics • Ray optics • Photonics
8	Integration in curriculum	semester: 1
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester

13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Agrawal, G.P.: Fiber Optic Communication Systems, Willey, New York, 1992 Kaminow, I, Li, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002 Kaminow, I, Li, T., Willner, A.: Optical Fiber Telecommunications VA, Academic Press, 2008

1	Module name 713618	Computer vision	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Tim Weyrich
5	Contents	This lecture discusses important algorithms from the field of computer vision. The emphasis lies on 3-D vision algorithms, covering the geometric foundations of computer vision, and central algorithms such as stereo vision, structure from motion, optical flow, and 3-D multiview reconstruction. Participants of this advanced course are expected to bring experience from prior lectures either from the field of pattern recognition or from the field of computer graphics.
6	Learning objectives and skills	Die Vorlesung stellt eine Auswahl von Methoden aus dem Gebiet der Computer Vision vor, die in dem Feld eine zentrale Stellung einnehmen. In den Übungen implementieren und evaluieren die Studierenden selbständig diese Methoden. Die Studierenden arbeiten die ganze Zeit über an populären Computer Vision-Methoden wie zum Beispiel Stereosehen, optischer Fluss und 3D-Rekonstruktion aus mehreren Ansichten. Für diese Probleme • beschreiben die Studierenden perspektivische Projektion, Rotationen und verwandte geometrische Grundlagen, • erklären die Studierenden die behandelten Methoden, • diskutieren die Studierenden Vor- und Nachteile verschiedener Modalitäten zur Erfassung von 3D-Informationen, • implementieren die Studierenden einzeln und gemeinschaftlich in Kleingruppen Code, • entdecken die Studierenden optimale Vorgehensweisen in der Datenaufnahme, • erkunden und bewerten die Studierenden unterschiedliche Möglichkeiten für die Evaluation, • diskutieren und präsentieren die Gruppenarbeiter in Gruppen die Vor- und Nachteile ihrer Implementierungen, • diskutieren und reflektieren die Studierenden gesellschaftliche Auswirkungen von Anwendungen des 3D-Rechnersehens. The lecture introduces computer vision algorithms that are central to the field. In the exercises, participants autonomously implement and evaluate these algorithms. The participants work throughout the time on popular computer vision algorithms, like for example stereo vision, optical flow, and 3-D multiview reconstruction. For these problems, the participants • describe perspective projection, rotations, and related geometric foundations, • explain the presented methods, • discuss the advantages and disadvantages of different modalities for acquiring 3-D information,

		• implement individually and in small groups code, • discover best practices in data acquisition, • explore and rank different choices for evaluation, • discuss and present in groups the advantages and disadvantages of their implementations, • discuss and reflect the social impact of applications of computer vision algorithms.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable (90 minutes) Dieses Modul wird mit einer Klausur (90 Minuten) geprüft. The form of examination is a written exam of 90 minutes.
11	Grading procedure	Variable (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Richard Szeliski: "Computer Vision: Algorithms and Applications", Springer 2011.

Sensing & Perception - Seminar & laboratory

1	Module name 97651	Laborpraktikum Image and Video Compression Laborpraktikum Multimediakommunikation	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	PD Dr. Christian Herglotz
5	Contents	Content • Introduction to MATLAB • Implementation of the single video codec processing blocks • Integration into the video codec pipeline, tests, and extensions • Participation in a subjective video test of selected implementations • Presentation and discussion of the achieved results
6	Learning objectives and skills	The students • create a fully functional program using the programming environment MATLAB, • evaluate the processing blocks of a typical video codec, • design their own video codec and enhance it by extensions of their choice, • evaluate their implemented video codecs in a subjective comparison, • reflect upon the methods conveyed during the laboratory.
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement The lab course comprises ten sessions of four hours plus two sessions of two hours, which include 7 work packages, a subjective test, and a final presentation. Each work package requires a preparation in written form and will be checked and reviewed (pass/fail) before the start of each session. During each of the ten mandatory lab sessions, the students are required to work on programming tasks, which will be reviewed at the end of each session (pass/fail). After these ten programming sessions, a working video codec has to be handed in. Besides, the students have to participate a subjective test, where the codec results are evaluated. In the last session, each video codec has to be presented by the students. A certificate confirming the successful participation in the laboratory is received if all work packages have been sufficiently prepared and implemented, if the results of all work packages have been combined into a functional and

		running video codec which is suitable for subjective testing, if the subjective video test has been participated in, and if the final video codec has been presented during the final presentation.
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 45 h Independent study: 30 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	The lab course notes will be distributed during the introductory meeting.

1	Module name 92344	Lab Course Image and Video Signal Processing on Embedded Systems Laboratory course: Image and video signal processing on embedded systems	2,5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	PD Dr.-Ing. Jürgen Seiler
5	Contents	Today, many image and video signal processing applications are running on embedded systems. However, the computational power and the energy storage is a limiting demand for embedded systems. Nevertheless, daily mobile devices like smartphone and tablet are able to perform signal processing tasks for image and video signals, for example coding of images and videos, the creation of a panorama or the calculation of images with high dynamic range. The image and video signal processing on embedded systems lab course should show the challenges that occur while handling with such mobile devices and the implementation of such algorithm on an embedded system. Therefore, Raspberry Pis as embedded systems and Python as coding language is used in the laboratory. The experiments include the setup of the Raspberry Pi, an introduction to Python and an introduction to image and video signal processing. In addition, a camera will be connected, signal processing will be done with the camera and digital filters are implemented. Moreover, the laboratory includes different computer vision applications like the creation of a panorama.
6	Learning objectives and skills	The students • understand the challenges of the embedded system • make use of the coding language Python for image and video signal processing algorithms • implement functional programs with Python • evaluate the blocks of computer vision algorithms • evaluate the self-implemented programs by subjective and objective comparison • reflect the learning process in the laboratory.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement
11	Grading procedure	Practical achievement (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h

14	Module duration	1 semester
15	Teaching and examination language	
16	Bibliography	The laboratory script "Image and video signal processing on embedded platforms will be handed out in the first session.

1	Module name 92335	Lab Course Digital Signal Processing Laboratory course: Digital signal processing	2,5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Dr.-Ing. Heinrich Löllmann
5	Contents	In this laboratory course the theory from the lecture Digital Signal Processing is applied in practice, using the programming environment MATLAB. The topics include quantization, spectral analysis, FIR and IIR filter design, filter banks and adaptive filters. The course consists of 5 guided experiments in which students work on programming problems in groups of two, and a 5-day block course where each group works on an individual project from the field of digital signal processing. The preparation, as well as the results of the past experiment will be examined by a short test at the beginning of each experiment. For passing the lab course, a minimum number of points from the tests and the project is required. The course requires previous experience in MATLAB programming. It is possible to take the course in parallel to the DSP lecture, however, revision of the relevant lecture contents before each lab lesson, and participation in the DSP exercises and tutorials is required.
6	Learning objectives and skills	The students • create MATLAB programs for the each experiments and, by this, apply knowledge acquired in the DSP lecture and supplement course • analyze and evaluate the implemented algorithms • understand the requirements for practical realizations of algorithms for digital signal processing • reflect the learning progress during the lab course.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement
11	Grading procedure	Practical achievement (100%)
12	Module frequency	no Module frequency information available!
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	

16	Bibliography	• Rinderknecht, S. (2018). Einführung in die Mechatronik für den Maschinenbau. Shaker. • Isermann, R. (2007). Mechatronische Systeme: Grundlagen. Springer. • Janocha, H. (Ed.). (2013). Aktoren: Grundlagen und Anwendungen. Springer

1	Module name 878210	Lab course machine learning in signal processing	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis
5	Contents	This is an advanced level lab course in machine learning. Imagine a car driving on an autobahn in an automatic mode. Among other things, the car needs to steer itself to keep driving in it's own lane. To accomplish this, the central problem is to detect the road-lane markings. These are the white solid or dashed lines that are drawn on each side of the lane. The standard modern approach to solve this type of problems is to take a large dataset of labeled examples and train a deep neural network model to accomplish the task. This is how car and pedestrian detection algorithms are developed. The difficulty with the road-lane markings is that there is no labeled dataset of them and creating such dataset would cost millions of dollars. In this lab course we will solve this problem using transfer learning and mathematical modeling: • Create cartoon-like artificial images of a road with known locations for the lane markings. • Train deep neural network on these artificial images with heavy data augmentations that mimic real-world images. • Create a dataset of unlabeled real-life videos by downloading and organizing examples from youtube. • Create a machine learning pipeline for working with these videos efficiently. • Apply the neural network that has been trained on artificial data to the real world videos. • Analyze the quality of results produced by the network. • Use mathematical modeling to correct the outputs of the network. • Retrain the network on the dataset composed of the corrected outputs. • Measure and analyze the quality of the results. The software will be written in Python using JupyterLab development framework. Access to modern GPU server will be provided. The best students will have the opportunity to contribute to the creation of state-of-the-art lane detection system for self-driving cars during or after the course.
6	Learning objectives and skills	Students are able to: • Independently design machine learning pipelines to solve complex problems in artificial intelligence. • Choose appropriate algorithms for the problem at hand.

		• Use standard packages for machine learning in Python: numpy, cvxpy, scikit-learn, pywavelets, pytorch. • Debug and calibrate machine learning algorithms. Develop modification to the standard algorithms as appropriate to the problem at hand. • Explain the theoretical aspects of deep learning.
7	Prerequisites	Knowledge of Python programming language is required. Basic theoretical knowledge in machine learning is assumed: consider taking the Machine Learning in Signal Processing (MLSIP) course in the same semester.
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Planning & Control - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement To pass the lab course, the programming tasks of each of the 5 session must be successfully completed.
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 15 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 92373	Seminar Wireless, Radar and Microwave Techniques Seminar: Wireless, radar and microwave techniques	2,5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Prof. Dr.-Ing. Martin Vossiek
5	Contents	In the seminar "Wireless, Radar and Microwave Techniques", current applications and research work from the field of wireless, radar and microwave technology are dealt with within a framework topic. The topics cover a wide range of modern wireless sensor, localization and communication technologies such as radar applications in traffic, imaging radar and wireless sensors in medical technology. The individual topics that can be worked on within the framework topic are presented in an introductory lecture and assigned to the students. To test presentation techniques, short presentations lasting 5 minutes are given in the second event, followed by a feedback round in which the design aspects are addressed. In the following weeks, each student independently undertakes research on his or her individual topic and prepares a half-hour presentation aimed at an interested professional audience. Each student is individually advised by a member of the department. Each lecture is followed by a 15-minute discussion round in which questions and additions to the previously discussed topic are asked. The lectures are given in weekly succession in the second half of the semester.
6	Learning objectives and skills	• In their research, the students record and organise the state of the art on the chosen framework topic from the field of wireless, radar and microwave techniques. • In doing so, they have to assess the relevance of various aspects of content for the intended audience, and structure the presentation effectively given the time constraints. • They then design and create a scientific/technical presentation that is suitable for effective knowledge transfer in the context of an oral presentation. • For this purpose, they evaluate different presentation options with regard to their comprehensibility. • They clarify questions that arise in the discussion round, and in doing so, explain the issue in question or identify suitable sources that are useful for further clarification. • They become familiar with RF applications and devices using practical examples and gain an insight into current research work in the field of RF technology. They are thus able to give scientific presentations in front of a specialist audience, to prepare even more complex topics clearly and to convey the specialist knowledge in an understandable

		way. The skills acquired serve, among other things, as a basis for final presentations in the context of bachelor's and master's theses and provide a foundation for future teamwork in the areas of research, teaching and industry.
7	Prerequisites	At least one of the following modules should be successfully completed: • Introduction to Microwave Engineering • Radar, RFID and Wireless Sensor Systems
8	Integration in curriculum	semester: 3
9	Module compatibility	Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Seminar achievement
11	Grading procedure	Seminar achievement (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	
16	Bibliography	Literature is provided on a topic-specific basis.

1	Module name 92336	Seminar on Selected Topics of Multimedia Communications and Signal Processing Seminar: Selected topics of multimedia communications and signal processing	2,5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis
5	Contents	The Seminar on Selected Topics of Multimedia Communications and Signal Processing deals with current research topics in the area of multimedia communications and signal processing. In an introductory meeting, the course of the seminar is outlined and each participant selects one of the offered topics. The participant should become familiar with the assigned research topic and present it by a report and a talk at the end of the seminar with the support of a supervisor. In an intermediate meeting about 5 weeks after the introductory meeting, the participants give a brief presentation about their topics and show first results. In addition, hints for the preparation of the final talk are provided at this meeting. At the end of the semester, a final one-day meeting takes place where each participant presents his topic in a talk of 30 minutes followed by a discussion and questions from the audience. In addition, each participant has to submit a report of about 10 pages about his topic a few days before the final meeting.
6	Learning objectives and skills	The students • acquire and apply fundamental techniques to conduct a literature survey, and to prepare and present a technical topic • analyze and evaluate provided literature regarding the focus of their technical presentation • apply the knowledge acquired during their studies to deepen by themselves their technical focus • apply acquired knowledge to ask a presenter questions and to discuss the presentation • analyze and evaluate the presentations of other seminar participants.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Seminar achievement The given presentation and submitted report are included in the grade.
11	Grading procedure	Seminar achievement (100%)
12	Module frequency	Every semester

13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 182405	Praktikum Architekturen der digitalen Signalverarbeitung Laboratory architectures for digital signal processing	2,5 ECTS
2	Courses / lectures	Praktikum: Praktikum Architekturen der digitalen Signalverarbeitung (3 SWS)	2,5 ECTS
3	Lecturers	Torsten Reißland	

4	Module coordinator	Prof. Dr.-Ing. Georg Fischer
5	Contents	• Aufbau einer akustischen FSK Datenverbindung • Einführung in die VHDL Programmierung eines FPGAs • Erzeugung einer PRBS Sequenz • Effiziente Implementierung eines Sinusgenerators mit Hilfe des Cordic Algorithmus • Digitale Filterung • Demodulation/Detektion
6	Learning objectives and skills	Die Studierenden erlangen Grundlagenkenntnisse in der Programmierung mit MATLAB und VHDL Die Studierenden sind in der Lage, eine digitales Datenübertragungssystem vom Sender bis zum Empfänger theoretisch zu konzeptionieren, in MATLAB zu simulieren und praktisch in VHDL auf einem FPGA umzusetzen Die Studierenden erhalten die theoretische und praktische Fähigkeit, digitale Signale zu definieren, zu verarbeiten, digitale Filter zu erzeugen und Signale mit diesen zu manipulieren Die Studierenden verstehen die Schnittstelle zwischen der digitalen und analogen Ebene und sind in der Lage, diese Schnittstellen auf einem FPGA Evaluation Board zu verwenden
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement Praktikumsleistung als Studienleistung (unbenotet): 2 Versuche ("Matlab Aufgaben" und "VHDL Aufgaben"). Je Versuch ist ein Protokoll (mit 3-5 Seiten) den erreichten Ergebnissen und dem funktionierenden selbständig erarbeitetem Programmcode abzugeben. Vor jedem Versuch erfolgt eine Überprüfung der ausreichenden Kenntnis der Versuchsbedingungen im Rahmen einer 5 minütigen mündlichen Prüfung
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 45 h Independent study: 30 h
14	Module duration	1 semester

15	Teaching and examination language	english
16	Bibliography	

1	Module name 97520	Laborpraktikum Digitale Signalverarbeitung	2,5 ECTS
2	Courses / lectures	Praktikum: Lab Course Digital Signal Processing (2 SWS)	2,5 ECTS
3	Lecturers	Dr.-Ing. Heinrich Löllmann Prof. Dr.-Ing. Sebastian Schlecht	

4	Module coordinator	Prof. Dr.-Ing. Walter Kellermann
5	Contents	In this laboratory course the theory from the lecture Digital Signal Processing is applied in practice, using the programming environment MATLAB. The topics include quantization, spectral analysis, FIR and IIR filter design, filter banks and adaptive filters. The course consists of 5 guided experiments in which students work on programming problems in groups of two, and a 5-day block course where each group works on an individual project from the field of digital signal processing. The preparation, as well as the results of the past experiment will be examined by a short test at the beginning of each experiment. For passing the lab course, a minimum number of points from the tests and the project is required. The course requires previous experience in Python programming. It is possible to take the course in parallel to the DSP lecture, however, revision of the relevant lecture contents before each lab lesson, and participation in the DSP exercises is strongly recommended.
6	Learning objectives and skills	The students • create functional Python programs for the individual pre-drawn experiments and apply the knowledge acquired in the lecture and exercise • analyze and evaluate the algorithm they have implemented • understand the requirements of practical implementations of digital signal processing algorithms • reflect on their own learning process during the lab course.
7	Prerequisites	Strongly recommended are courses on signals and systems
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement Students must successfully complete 5 experiments and then work on a scientific project in groups of two, about which a 3 to 4-page documentation must be prepared. At the beginning of each experiment, the status of the preparation and the experimental results of the previous session are checked in a written test. To pass the lab course, a minimum number of points from the tests and the group project is required.

11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	The script for this lab course will be handed out at the introductory meeting. Moreover, the following books are recommended • J.G. Proakis, D.G. Manolakis: Digital Signal Processing. 4th edition. Prentice Hall, Englewood Cliffs, NJ, 2007. • A.V. Oppenheim, R.V. Schaffer: Digital Signal Processing. Prentice Hall, Englewood Cliffs, NJ, 1975. • K.D. Kammeyer, K. Kroschel: Digitale Signalverarbeitung: Filterung und Spektralanalyse mit MATLAB®-Übungen . 8. Aufl. Teubner, Stuttgart, 2012

1	Module name 914949	Seminar Ausgewählte Kapitel der Multimediakommunikation und Signalverarbeitung Seminar on selected topics of multimedia communications and signal processing	2,5 ECTS
2	Courses / lectures	Seminar: Seminar Ausgewählte Kapitel der Multimediakommunikation und Signalverarbeitung (2 SWS) Participation at each session of the seminar is mandatory.	2,5 ECTS
3	Lecturers	Marc Hölle Michele De Vita Prof. Dr. Vasileios Belagiannis	

4	Module coordinator	Prof. Dr.-Ing. Andre Kaup
5	Contents	The Seminar on Selected Topics of Multimedia Communications and Signal Processing deals with current research topics in the area of multimedia communications and signal processing. In an introductory meeting, the course of the seminar is outlined and each participant selects one of the offered topics. The participant should become familiar with the assigned research topic and present it by a report and a talk at the end of the seminar with the support of a supervisor. In an intermediate meeting about 5 weeks after the introductory meeting, the participants give a brief presentation about their topics and show first results. In addition, hints for the preparation of the final talk are provided at this meeting.
6	Learning objectives and skills	The students • acquire and apply fundamental techniques to conduct a literature survey, and to prepare and present a technical topic • analyze and evaluate provided literature regarding the focus of their technical presentation • apply the knowledge acquired during their studies to deepen by themselves their technical focus • apply acquired knowledge to ask a presenter questions and to discuss the presentation • analyze and evaluate the presentations of other seminar participants.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Seminar achievement At the end of the semester, a final one-day meeting takes place where each participant presents his topic in a talk of 30 minutes followed by a discussion and questions from the audience. In addition, each participant has to submit a report of about 10 pages about his topic a few days before the final meeting.

11	Grading procedure	Seminar achievement (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 97525	Laborpraktikum Bild- und Videosignalverarbeitung auf eingebetteten Plattformen Laboratory course: Image and video signal processing on embedded platforms	2,5 ECTS
2	Courses / lectures	Praktikum: Laborpraktikum Bild- und Videosignalverarbeitung auf eingebetteten Plattformen (3 SWS)	2,5 ECTS
3	Lecturers	Alexander Kopte PD Dr.-Ing. Jürgen Seiler	

4	Module coordinator	Prof. Dr.-Ing. Andre Kaup
5	Contents	Today, many image and video signal processing applications are running on embedded systems. However, the computational power and the energy storage is a limiting demand for embedded systems. Nevertheless, daily mobile devices like smartphone and tablet are able to perform signal processing tasks for image and video signals, for example coding of images and videos, the creation of a panorama or the calculation of images with high dynamic range. The image and video signal processing on embedded systems lab course should show the challenges that occur while handling with such mobile devices and the implementation of such algorithm on an embedded system. Therefore, Raspberry Pis as embedded systems and Python as coding language is used in the laboratory. The experiments include the setup of the Raspberry Pi, an introduction to Python and an introduction to image and video signal processing. In addition, a camera will be connected, signal processing will be done with the camera and digital filters are implemented. Moreover, the laboratory includes different computer vision applications like the creation of a panorama.
6	Learning objectives and skills	The students • understand the challenges of the embedded system • make use of the coding language Python for image and video signal processing algorithms • implement functional programs with Python • evaluate the blocks of computer vision algorithms • evaluate the self-implemented programs by subjective and objective comparison • reflect the learning process in the laboratory.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement The laboratory is based on nine experiments, which are described in the laboratory script. Every experiment has to be prepared at home and will be checked before every experiment. The results of the prepared tasks in the laboratory will be checked at the end

		of the experiment. For this, the participants have to explain their developed results to the supervisors. The laboratory is passed if all nine experiments are successfully completed.
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 15 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	The laboratory script "Image and video signal processing on embedded platforms will be handed out in the first session.

1	Module name 97690	Laborpraktikum Sensorik Laboratory course: Sensor technology	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Philipp Beckerle
5	Contents	no content description available!
6	Learning objectives and skills	no learning objectives and skills description available!
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Sensing & Perception - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	no Module frequency information available!
13	Workload in clock hours	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
14	Module duration	?? semester (no information for Module duration available)
15	Teaching and examination language	german
16	Bibliography	

Technical elective module

1	Module name 42919	Power electronics for decentral energy systems Power electronics for decentralized energy systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Thomas Eberle
5	Contents	ENGLISH DESCRIPTION: • Introduction, motivation • AC vs. DC grids, DC grid topologies • Application examples, voltage levels • Protection and earthing concepts • Control methods for local DC grids • Modeling the frequency characteristic of switch-mode converters • Impedance measuring under load • Stability analysis in DC grids Components of local DC grids: • Battery storages (technologies, technical properties, electrical impedance characteristics and equivalent circuits, battery management, monitoring and protection systems (BMS)) • Regenerative power sources (PV, fuel cells) and their electrical characteristics • Non-isolating DC/DC converters (basic topologies and properties) • Isolating DC converters (basic topologies and properties) • AC/DC converter (basic topologies and properties) • Switches, plugs and protection devices for DC grids • Arc discharges and their characteristics DEUTSCHE INHALTSBESCHREIBUNG Einführung • Netztopologien • Spannungsebenen, Schutz- und Erdungskonzepte • Anwendungsbeispiele Komponenten lokaler Gleichspannungsnetze • Batteriespeicher (Technologien, Eigenschaften, elektrisches Impedanzverhalten, Ersatzschaltbilder, Schutz- und Überwachungsschaltungen) • Elektrischen Eigenschaften regenerativer Stromquellen (PV, Brennstoffzellen) • Nicht isolierende Gleichspannungswandler (Grundlagen, Topologien) • Isolierende Gleichspannungswandler (Grundlagen, Topologien) • AC/DC-Wandler (Grundlagen, Topologien) • Schalter, Stecker und Schutzgeräte für Gleichspannung, Lichtbogeneigenschaften Regelung lokaler Gleichspannungsnetze und Stabilitätsanalyse

		• Regelverfahren für Gleichspannungsnetze • Verfahren zur Impedanzmessung unter Last • Modellierung des Frequenzverhaltens von Schaltwandlern und Netzen • Analyse des Stabilitätsverhaltens
6	Learning objectives and skills	ENGLISH DESCRIPTION: Students who participate in this course will become familiar with the basics of decentral energy systems, their components and operation. After successfully completing this module, students: • know the structure and topologies of local low-voltage direct current grids, the most important properties and error scenarios • know the electrical properties of battery storage and regenerative power sources • know the basic circuits of the various power electronic converters in a DC grid (DC / DC and AC / DC converters), their advantages and disadvantages • understand the arc problem • know solutions for the implementation of DC-compatible plugs, switches and protective devices • know procedures for controlling decentral DC grids • can model switch-mode converters and grids with regard to their dynamic behavior • know procedures for impedance measurement in grids "under load" • can carry out stability studies on DC grids • are familiar with modern device power supply solutions using protective extra-low voltage During the practicum students learn: • dealing with power electronics measurement equipment • measuring typical characteristics and important parameters of a power electronic circuit • how to avoid the most common measurement problems • safety rules when dealing with power electronics GERMAN DESCRIPTION: Die Studierenden • kennen den Aufbau und die Topologien lokaler Niederspannungs-Gleichstromnetze, die wichtigsten Eigenschaften und Fehlerszenarien • kennen die elektrischen Eigenschaften von Batteriespeichern und regenerativen Stromquellen • kennen die Grundsaltungen der verschiedenen leistungselektronischen Wandler in einem Gleichspannungsnetz (DC/DC- und AC/DC-Wandler) • analysieren die Schaltungsoptionen bezüglich ihrer Vor- und Nachteile • verstehen die Lichtbogenproblematik

		• kennen Lösungen zur Realisierung von gleichspannungstauglichen Steckern, Schaltern und Schutzgeräten • kennen Verfahren zur Regelung lokaler Gleichspannungsnetze • können Schaltwandler und Netze bezüglich ihres dynamischen Verhaltens modellieren • kennen Verfahren zur Impedanzmessung in Netzen unter Last" • können Stabilitätsbetrachtungen an Gleichspannungsnetzen durchführen • kennen moderne Gerätestromversorgungslösungen mit Schutzkleinspannung
7	Prerequisites	Recommended/Empfohlen: • Fundamentals of Electrical Engineering I-III, Power Electronics • Grundlagen der Elektrotechnik I-III, Leistungselektronik
8	Integration in curriculum	semester: 6
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Die Prüfung richtet sich nach dem didaktischen Charakter des Moduls und umfasst entweder eine mündliche Prüfung von 30 min oder eine Klausur von 90 min Dauer. Die Entscheidung für eine Prüfungsform wird in Semestern, in denen die Lehrveranstaltungen stattfinden, spätestens zwei Wochen nach Vorlesungsbeginn in der Lehrveranstaltung bzw. den Lehrveranstaltungen und in der StudOn-Gruppe bekannt gegeben. In Semestern, in denen keine Lehrveranstaltungen stattfinden, wird die Prüfungsform spätestens zwei Monate vor der Wiederholungsprüfung durch E-Mail an die angemeldeten Prüflinge bekannt gegeben.
11	Grading procedure	Written examination (100%) 100%
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german english
16	Bibliography	• Lecture Notes • "Power Electronics for Distributed Power Supply - DC Networks" • Skript zur Vorlesung • "Leistungselektronik für dezentrale Energieversorgung - Gleichspannungsnetze"

1	Module name 43700	Transportprozesse Transport processes	5 ECTS
2	Courses / lectures	Vorlesung: Transportprozesse (2 SWS) Übung: Transportprozesse Übung (1 SWS)	3 ECTS 2 ECTS
3	Lecturers	Rafael Clemente Mallada Dr.-Ing. Sebastian Rieß Nicklas Lindacher Prof. Dr.-Ing. Michael Wensing	

4	Module coordinator	Dr.-Ing. Sebastian Rieß Prof. Dr.-Ing. Michael Wensing
5	Contents	• Transportvorgänge: Wärme-, Stoff-, und Impulsübertragung • Auf Basis der kinetischen Gastheorie werden Gleichungen zur Beschreibung von Transportvorgängen (allgemeine Transportgleichung, Fourier'sches Gesetz, Fick'sche Gesetze,) hergeleitet und für in der Technik typischen Geometrien und Randbedingungen angewandt • Herleitung von Gleichungen zur Beschreibung technischer Aufgabenstellung • Aufbereitung von Problemstellungen zur Lösung mit Rechnerunterstützung
6	Learning objectives and skills	Die Studierenden • haben vertiefende Kenntnisse in der Impuls-, Wärme, und Stoffübertragung • können Gleichungen zur Beschreibung technischer Aufgabenstellungen eigenständig herleiten • bereiten Aufgabenstellung zur Lösung am Rechner z.B. mit Hilfe von MatLab auf • erarbeiten projektbezogener Aufgaben am Beispiel von Miniprojekten
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written or oral (120 minutes) variabel: mündlich oder schriftlich
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 45 h Independent study: 105 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 44000	Test integrierter Schaltungen	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Klaus Helmreich
5	Contents	Motivation Damit unsere elektronischen Geräten überhaupt funktionieren, muß jede einzelne mikroelektronische Schaltung darin nach ihrer Fertigung geprüft werden. Wegen der Komplexität heutiger integrierter Schaltungen (ICs) machen diese Tests bis zur Hälfte der Fertigungskosten aus! - Ein guter Grund, sich mit dem Thema Test auseinanderzusetzen, wenn man sich mit Mikroelektronik befaßt. Gliederung Die Vorlesung umfaßt Inhalte zu Bedeutung, Theorie, Methodik, Gerätetechnik und Praxis des Tests in der Halbleiterfertigung. 1 Test in der Halbleiterfertigung Herstellungsphasen integrierter Schaltungen, wirtschaftliche Bedeutung des Tests, Testsysteme, Zuführungs- und Sortierautomaten, Prüfadapter für montierte ICs und Wafer, Kontakttechnologien für Wafertest, Modulare Testsysteme 2 Messen und Testen Begriffe und Definitionen, Meßunsicherheit und Irrtumsrisiko, Schätzung von statistischen Parametern: Mittelwert, Streuwert, Konfidenzintervalle, Rechnen mit statistischen Schätzwerten, Entscheidungsfindung bei Irrtumsrisiken, Hypothesentest der mathematischen Statistik als theoretische Grundlage des Fertigungstests, Schließen aus statistischen Aussagen 3 Fehler und Tests Definition, Klassifizierung hinsichtlich Entstehung und Auswirkung, Test im Herstellungsprozess und während des Produktlebens, Randbedingungen verschiedener Testaufgaben 4 Testkosten und Prüfstrategie Wirtschaftlichkeitsbetrachtungen, Zehner-Regel, Testkosten und Testgüte, Testkomplexität, Maßzahlen: Fehlerwahrscheinlichkeit, Ausbeuten, Fehlerüberdeckung, Testschlupf und Ausbeuteverlust 5 Testkategorien und Testerzeugung Notwendigkeit des Produktionstests, Defekte und Fehler, Zuverlässigkeitstest, Simulation und Test, Testentwurf, Bestandteile von Fertigungstests, Funktionstest und Strukturtest, Fehlermodelle, Testmustererzeugung durch Fehlersimulation und synthetische Verfahren, Fehlerklassen und Fehlerkatalog, redundante Fehler, D-Kalkül 6 Testsysteme Entstehungsgeschichte, Funktionsprinzip, Einteilung nach Einsatzbereich und Prüflingskategorie, Leistungsmerkmale und Aufbau, Pinelektronik

		7 Prüfprogramm und Testsignalbeschreibung Zyklisierung und Prüftakt, Prüfmuster, Zeitmarken, Testsystemarchitekturen, Signalformate 8 Test gemischt analog-digitaler Schaltungen (Mixed-Signal Test) Instrumentierung, digitale Signalverarbeitung, Kohärentes Testen, Parameter gemischt analog-digitaler Schaltungen, spektrale und Histogrammtests, Testabläufe 9 Test weiterer Schaltungsklassen Speichertest: Fehlermodell, Prüfverfahren, algorithmische Mustergenerierung und Redundanzanalyse, Test von Hochfrequenzschaltungen: Instrumentierung und Besonderheiten, synthetische Instrumente, System-on-Chip- / System-In-Package-Test 10 Testfreundlicher Entwurf (Design for Testability) Begriff, Kosten, Standardisierung, Systematik der Verfahren, Ad-hoc-Methoden, Stimulusgenerierung und Signaturanalyse, Prüfpfadverfahren, Selbsttest
6	Learning objectives and skills	Fachkompetenz Wissen die wesentlichen Geräte und Komponenten für den Produktionstest integrierter Schaltungen nennen und erläutern Verstehen • Prüfergebnisse als wahrscheinlichkeitsbehaftete Aussagen verstehen • technische und wirtschaftliche Erfordernisse beim Halbleitertest erläutern und entsprechende Abwägungen darstellen • technisch-wirtschaftliche Kenngrößen definieren und deren Zusammenhänge darstellen • Fehlermodelle beschreiben und deren Bedeutung für die Testsynthese darstellen • Verfahren zur automatischen Testmustererzeugung unterscheiden und beschreiben • Funktionsprinzip von Testsystemen und deren Komponenten erläutern • Komponenten der Testsignalbeschreibung zusammenstellen • Methoden des prüffreundlichen Entwurfs darstellen Anwenden • Vorgänge "Messen" und "Prüfen" voneinander abgrenzen und den Zusammenhang zwischen Meßunsicherheit und Irrtumsrisiko erklären • Mittelwerte und Streuwerte aus Meßdaten schätzen und für diese Konfidenzintervalle zu gegebener Irrtumswahrscheinlichkeit angeben • die Unsicherheit von aus meßunsicherkeitsbehafteten Anfangsgrößen berechneten Ergebnissen berechnen • sich der Denkfallen beim Schließen aus statistischen Aussagen bewußt sein • Prüfsignale anhand der Kriterien für kohärentes Testen definieren

		Analysieren • Fehler in technischen Produkten hinsichtlich Entstehung und Auswirkung klassifizieren • Testvorgänge an integrierten Schaltungen klassifizieren und zugehörige Randbedingungen nennen • Begriffe Defekt" (defect), Fehler" (fault), Irrtum" (error), Ausfall" (failure) am Beispiel Halbleitertest voneinander abgrenzen • Abläufe bei Halbleitertests hinsichtlich verschiedener Kriterien (hierarchisch) strukturieren und unterscheiden • Testsysteme und deren Architekturen hinsichtlich verschiedener Kriterien klassifizieren Evaluiere (Beurteilen) • technische und wirtschaftliche Bedeutung des Tests im Vergleich zu weiteren Bereichen der Halbleiterindustrie zutreffend einschätzen • Prüfkriterien anhand angestrebter Qualitätsanforderungen (Testschlupf) aufstellen • Testschwellen im Hinblick auf Minimierung einer Irrtumswahrscheinlichkeit wählen Erschaffen (keine) Lern- bzw. Methodenkompetenz Lernziele hinsichtlich Lern- und Arbeitsmethoden: Hypothesen statistisch prüfen, wahrscheinlichkeitsbehaftete Aussagen interpretieren Selbstkompetenz Lernziele hinsichtlich persönlicher Weiterentwicklung: Schlüsse aus statistischen Aussagen und Ergebnissen hinterfragen diesen kritisch begegnen Sozialkompetenz Lernziele hinsichtlich des Umgangs mit Menschen: • Übungsaufgabenstellungen gemeinsam in Kleingruppen lösen
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 47656	Legged Locomotion of Robots (LLR) Legged locomotion of robots (LLR)	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Anne Koelewijn
5	Contents	Legged robotics help researchers understand human and animal locomotion. Furthermore, legged robots have many different applications, for example to aid in dangerous environments and in rehabilitation. Active prosthetics and exoskeletons improve gait of people with a disability, like a spinal cord injury or an amputation. The goal of this seminar is to become familiar with different algorithms and analysis methods that are used for legged robotics. Important concepts here are the energetics and the stability. Robots should be energy efficient, in the case of an exoskeleton to not lose battery power for a day. Obviously, stability is important to avoid falls. Each student will perform a literature review of a specific concept related to robot locomotion. The concepts can be chosen from a list, or the student can propose their own topic. Students can choose to perform an extra assignment to receive an additional 2.5 ECTS. The assignment will require the student to implement the chosen concept in simulation or in practice.
6	Learning objectives and skills	- Familiarize with different concepts that are used in control and analysis of robot locomotion - Understand the theoretical background of concepts of robot locomotion - Differentiate between different types of robots - Understand the stability and energetics in robot locomotion
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Planning & Control - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Seminar achievement
11	Grading procedure	Seminar achievement (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 47657	Legged Locomotion of Robots + Laborprojekt (LLR-L) Legged locomotion of robots + laboratory project (LLR-L)	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Anne Koelewijn
5	Contents	Legged robotics help researchers understand human and animal locomotion. Furthermore, legged robots have many different applications, for example to aid in dangerous environments and in rehabilitation. Active prosthetics and exoskeletons improve gait of people with a disability, like a spinal cord injury or an amputation. The goal of this seminar is to become familiar with different algorithms and analysis methods that are used for legged robotics. Important concepts here are the energetics and the stability. Robots should be energy efficient, in the case of an exoskeleton to not lose battery power for a day. Obviously, stability is important to avoid falls. Each student will perform a literature review of a specific concept related to robot locomotion. The concepts can be chosen from a list, or the student can propose their own topic. In addition, students will do a lab project. This will require the student to implement the chosen concept in simulation or in practice.
6	Learning objectives and skills	Fachkompetenz Wissen • ◦ The students understand the theoretical background of concepts of robot locomotion. ◦ The students are able to differentiate between different concepts of robot locomotion. ◦ The students are able to understand the stability and energetics in robot locomotion. ◦ The students are able to transfer their knowledge about robot locomotion to new use cases. Analysieren The students are able to analyse and discuss new ideas and research potentials for robot locomotion.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Seminar achievement
11	Grading procedure	Seminar achievement (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h

		Independent study: 120 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 48432	Game theory with Applications to Information Engineering	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Thiess Büttner
5	Contents	The course is an introduction to the fundamentals of game theory and mechanism design. Motivations are drawn from topics in information engineering and networked systems (e.g. incentive-compatible/dynamic resource allocation in networks, distributed control of wireline and wireless communication networks, multi-agent systems, pricing and investment decisions in the Internet). Also social and economic contexts will be covered in order to put the engineering applications into a broader perspective. The course emphasizes theoretical foundations of game theory and develops knowledge on the standard equilibrium notions in different environments.
6	Learning objectives and skills	Students acquire a more formal understanding of game theoretical concepts and learn to differentiate between different types of games and their appropriate solution concepts, including Strategic Form Games, Dynamic Games with Complete Information, Static Games with Incomplete Information, and Dynamic Games with Incomplete Information. They learn the applications of these concepts to real-world multi-person decision problems and to give predictions based on the equilibrium concepts studied in the course.
7	Prerequisites	Basic knowledge of game theory and its core applications
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (60 minutes) The exam covers all materials from the lectures and exercise classes.
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german english
16	Bibliography	Main: Fudenberg, D. and Tirole, J. (2007), Game Theory, Cambridge, MIT Press.

	Further:
	Osborne, M. and Rubenstein, A. (1994), A Course in Game Theory, Cambridge, MIT Press.

1	Module name 65718	Introduction to Machine Learning Introduction to machine learning	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Andreas Maier
5	Contents	Das Modul hat zum Ziel, die Studierenden mit dem prinzipiellen Aufbau eines Mustererkennungssystems vertraut zu machen. Es werden die einzelnen Schritte von der Aufnahme der Daten bis hin zur Klassifikation von Mustern erläutert. Das Modul beginnt dabei mit einer kurzen Einführung, bei der auch die verwendete Nomenklatur eingeführt wird. Die Analog-Digital-Wandlung wird vorgestellt, wobei der Schwerpunkt auf deren Auswirkungen auf die weitere Signalanalyse liegt. Im Anschluss werden gebräuchliche Methoden der Vorverarbeitung beschrieben. Ein wesentlicher Bestandteil eines Mustererkennungssystems ist die Merkmalsextraktion. Verschiedene Ansätze zur Merkmalsberechnung/-transformation werden gezeigt, darunter Momente, Hauptkomponentenanalyse und Lineare Diskriminanzanalyse. Darüber hinaus werden Möglichkeiten vorgestellt, Merkmalsrepräsentationen direkt aus den Daten zu lernen. Das Modul schließt mit einer Einführung in die maschinelle Klassifikation. In diesem Kontext wird der Bayes- und der Gauss-Klassifikator besprochen. The module aims to familiarize students with the basic structure of a pattern recognition system. The individual steps from the acquisition of data to the classification of patterns are explained. The module starts with a short introduction, which also introduces the used nomenclature. Analog-to-digital conversion is introduced, with emphasis on its impact on further signal analysis. Common methods of preprocessing are then described. An essential component of a pattern recognition system is feature extraction. Various approaches to feature computation/ transformation are demonstrated, including moments, principal component analysis, and linear discriminant analysis. In addition, ways to learn feature representations directly from the data are presented. The module concludes with an introduction to machine classification. In this context, the Bayes and Gauss classifiers are discussed. T
6	Learning objectives and skills	Die Studierenden • erklären die Stufen eines allgemeinen Mustererkennungssystems • verstehen Abtastung, das Abtasttheorem und Quantisierung • verstehen und implementieren Histogrammequalisierung und -dehnung • vergleichen verschiedene Schwellwertmethoden • verstehen lineare, verschiebungsinvariante Filter und Faltung

		• wenden verschiedene Tief- und Hochpassfilter sowie nichtlineare Filter an • wenden verschiedene Normierungsmethoden an • verstehen den Fluch der Dimensionalität • erklären verschiedene heuristische Merkmalsberechnungsmethoden, z.B. Projektion auf einen orthogonalen Basisraum, geometrische Momente, Merkmale basierend auf Filterung • verstehen analytische Merkmalsberechnungsmethoden, z.B. Hauptkomponentenanalyse, Lineare Diskriminanzanalyse • verstehen die Basis von Repräsentationslernen • erläutern die Grundlagen der statistischen Klassifikation (Bayes-Klassifikator) • benutzen die Programmiersprache Python, um die vorgestellten Verfahren der Mustererkennung anzuwenden • lernen praktische Anwendungen kennen und wenden die vorgestellten Algorithmen auf konkrete Probleme an The students • explain the stages of a general pattern recognition system • understand sampling, the sampling theorem, and quantization • understand and implement histogram equalization and expansion • compare different thresholding methods • understand linear, shift invariant filters and convolution • apply various low-pass, high-pass, and nonlinear filters • apply different normalization methods • understand the curse of dimensionality • explain different heuristic feature calculation methods, e.g. projection on an orthogonal base space, geometric moments, features based on filtering • understand analytical feature computation methods, e.g. principal component analysis, linear discriminant analysis • understand the basis of representation learning • explain the basics of statistical classification (Bayes classifier) • use the programming language Python to apply the presented pattern recognition methods • learn practical applications and apply the presented algorithms to concrete problems
7	Prerequisites	Ein Mustererkennungssystem besteht aus den folgenden Stufen: Aufnahme von Sensordaten, Vorverarbeitung, Merkmalsextraktion und maschinelle Klassifikation. Dieses Modul beschäftigt sich in erster Linie mit den ersten drei Stufen und schafft damit die Grundlage für weiterführende Module (Pattern Recognition und Pattern Analysis). A pattern recognition system consists of the following stages: Sensor Data Acquisition, Preprocessing, Feature Extraction, and Machine Classification. This module primarily deals with the first three stages and

		thus creates the basis for more advanced modules (Pattern Recognition and Pattern Analysis).
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (60 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• Vorlesungsfolien/lecture slides • Heinrich Niemann: Klassifikation von Mustern, 2. überarbeitete Auflage, 2003 • Sergios Theodoridis, Konstantinos Koutroumbas: Pattern Recognition, 4. Auflage, Academic Press, Burlington, 2009 • Richard O. Duda, Peter E. Hart, David G. Stock: Pattern Classification, 2. Auflage, John Wiley & Sons, New York, 2001

1	Module name 86681	E-Learning Angebot: PC-Praktikum E-Learning: PC skills	2,5 ECTS
2	Courses / lectures	Tutorium: Tutorium zum PC-Praktikum (0 SWS) Praktikum: PC-Praktikum (4 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr. Sven Laumer	

4	Module coordinator	
5	Contents	no content description available!
6	Learning objectives and skills	no learning objectives and skills description available!
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (60 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	no Module frequency information available!
13	Workload in clock hours	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
14	Module duration	?? semester (no information for Module duration available)
15	Teaching and examination language	german
16	Bibliography	

1	Module name 92290	Kommunikationsnetze Communication networks	5 ECTS
2	Courses / lectures	Übung: Supplements Communication Networks (2 SWS) Vorlesung: Communication Networks (2 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr.-Ing. Andre Kaup Lena Eichermüller	

4	Module coordinator	Prof. Dr.-Ing. Andre Kaup
5	Contents	*Hierarchische Strukturen von Netzfunktionen* OSI-Schichtenmodell, Kommunikation im OSI-Modell, Datenstrukturen, Vermittlungseinrichtungen * Datenübertragung von Punkt zu Punkt* Signalverarbeitung in der physikalischen Schicht, synchrones und asynchrones Multiplex, Verbindungsarten *Zuverlässige Datenübertragung* Fehlervorwärtskorrektur, Single-Parity-Check-Code, Stop-and-Wait-ARQ, Go-back-N-ARQ, Selective-Repeat-ARQ *Vielfachzugriffsprotokoll* Polling, Token Bus und Token Ring, ALOHA, slotted ALOHA, Carrier-Sensing-Verfahren *Routing* Kommunikationsnetze als Graphen, Fluten, vollständiger Baum und Hamilton-Schleife, Dijkstra-Algorithmus, Bellman-Ford-Algorithmus, statisches Routing mit Alternativen *Warteraumtheorie* Modell und Definitionen, Littles Theorem, Exponentialwarteräume, Exponentialwarteräume mit mehreren Bedienstationen, Halbexponentialwarteräume *Systembeispiel Internet-Protokoll* Internet Protokoll (IP), Transmission Control Protocol (TCP), User Datagram Protocol (UDP) *Multimedianeetze* Klassifikation von multimedialen Anwendungen, Codierung von Multimediadaten, Audio- und Video-Streaming, Protokolle für interaktive Echtzeit-Anwendungen (RTP, RTCP), Dienstklassen und Dienstgütegarantien
6	Learning objectives and skills	Die Studierenden • verstehen den hierarchischen Aufbau von digitalen Kommunikationsnetzen • unterscheiden grundlegende Algorithmen für zuverlässige Datenübertragung mit Rückkanal und beurteilen deren Leistungsfähigkeit • analysieren Protokolle für Vielfachzugriff in digitalen Kommunikationsnetzen und berechnen deren Durchsatz • unterscheiden Routingverfahren und berechnen optimale Vermittlungswege für beispielhafte Kommunikationsnetze

		• abstrahieren und strukturieren Warteräume in Kommunikationsnetzen und berechnen maßgebliche Kenngrößen wie Aufenthaltsdauer und Belegung • verstehen grundlegende Mechanismen für die verlustlose und verlustbehaftete Codierung von Mediendaten • kennen die maßgeblichen Standards des Internets für Sicherung, Vermittlung und Transport von digitalen Daten
7	Prerequisites	Kenntnisse über Grundbegriffe der Stochastik
8	Integration in curriculum	semester: 5
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	M. Bossert, M. Breitbach, "Digitale Netze", Stuttgart: Teubner-Verlag, 1999

1	Module name 92357	Entwurf von mobilen Sensorsystemen und Knoten Design of mobile sensor systems and nodes	2,5 ECTS
2	Courses / lectures	Vorlesung: Entwurf von mobilen Sensorsystemen und -knoten (2 SWS)	2,5 ECTS
3	Lecturers	Benedict Scheiner	

4	Module coordinator	Fabian Michler Benedict Scheiner
5	Contents	• Sensortypen (low-power, resiliente Sensorsysteme) • Entwurfswerkzeuge (Simulationsprogramme (SPICE, Altium,...)) • Layout - EMV-Thematiken - Bauteilauswahl, Substratauswahl, parasitäre Effekte • HF-Schnittstelle zur Datenübertragung • Analoge Signalkonditionierung • AD-Umsetzung und Signalverarbeitung • Programmierbare Digitalssysteme (uC/FPGA) • Power-Management • Testumgebung (SCPI, Channel-Sounding)
6	Learning objectives and skills	Fachkompetenz Wissen Die Notwendigkeit verschiedener Sensorsysteme und wissen wie verschiedene Entwurfswerkzeuge anzuwenden sind. Verstehen Den Zusammenhang der einzelnen Systemkomponenten zueinander Anwenden Die Studierenden können mobile Sensorsysteme implementieren, erklären und einordnen. Erschaffen Studierende sind in der Lage anwendungsspezifische Sensorknoten zu planen und zu kreieren.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral Mündliche Prüfung, 30min
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german

1	Module name 92400	Optische Übertragungstechnik Optical communication systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Bernhard Schmauß
5	Contents	Kommerzielle Optische Kommunikationssysteme erreichen pro Faser Übertragungskapazitäten von mehreren Tbit/s. Im Labor wurden mehr als 100Tbit/s nachgewiesen. Die Realisierung derartiger Systeme setzt die Beherrschung verschiedenster Techniken der optischen Übertragungstechnik voraus. In der Vorlesung werden Techniken des Zeitbereichs - (TDM) und Wellenlängenmultiplex (WDM), aber besonders auch der Auslegung der Übertragungsstrecke (Link Design) auf der Basis entsprechender physikalischer und signaltheoretischer Grundlagen behandelt und vertieft. Dabei werden Verfahren besprochen, die sicherstellen, dass sowohl die Signalverzerrungen durch lineare und nichtlineare Fasereffekte als auch die Akkumulation des Verstärkerrauschens begrenzt bleiben. Es wird ausführlich die Systemoptimierung hinsichtlich des optischen Signal-Rausch-Verhältnisses (OSNR) diskutiert sowie auf Techniken des Dispersions- und Nichtlinearitätsmanagements (z.B. Solitonenübertragung) eingegangen. Hierbei wird dem Themenkomplex einer optimalen Streckenauslegung besonders eingehend behandelt. In der Folge werden verschiedene, gebräuchliche Modulationsverfahren einschließlich kohärenter Übertragungsverfahren behandelt, die in neueren Systemen eingesetzt und in experimentellen Systemen getestet werden. Eine Besprechung optischer Verfahren zur Signalregeneration bildet die Brücke zu aktuellen eigenen Forschungsarbeiten. Die vermittelten Grundlagen werden in der Übung zur Vorlesung durch praxisnahe und anschauliche Simulationsbeispiele vertieft.
6	Learning objectives and skills	Die Studierenden • besitzen spezialisiertes und vertieftes Wissen über die Konzeption und Struktur verschiedener optischer Übertragungssysteme. • können die Qualität optischer Datensignale im Kontext verschiedener Systemkonzepte vergleichen und bewerten • sind in der Lage Streckenauslegungen zu entwickeln und zu optimieren. • besitzen methodische Kenntnis zur Bestimmung und Verbesserung der Leistungsfähigkeit optischer Übertragungsstrecken unter Einbeziehung aktueller wissenschaftlicher Ergebnisse.
7	Prerequisites	Komponenten optischer Kommunikationssysteme hilfreich aber nicht obligatorisch
8	Integration in curriculum	semester: 6

9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	Agrawal, G.P.: Fiber-Optic Communication Systems, John Wiley & Sons, 1997 Agrawal, G.P.: Nonlinear Fiber Optics, John Wiley & Sons, 3. Auflage, 2001 Kaminow, I, Koch, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002 Skriptum zur Vorlesung Kaminow, I, Li, T., Willner, A.: Optical Fiber Telecommunications VA, Academic Press, 2008

1	Module name 92502	Grundlagen der optoelektronischen Bauelemente Basics of optoelectronic components	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Bernd Witzigmann
5	Contents	Funktionsweise von LEDs, Solarzellen, Transistoren, Dioden sowie Grundlagen der mikroskopischen Beschreibung
6	Learning objectives and skills	Fachkompetenz Wissen • Beherrschung der mikroskopischen Mechanismen für Ladungsträgertransport in Bauelementen • Zusammenhang der internen Bauelementephysik mit Systemspezifikationen der Anwendungen • Aufbau und Funktionsweise von LEDs, Solarzellen, Dioden und deren Materialien
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Klausur, schriftlich, Dauer 60 min
11	Grading procedure	Written examination (100%) 100% der Klausur
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	• Wuerfel, Solarzellen • Schubert, Light Emitting Diodes • Cohen Tannoudji, Quantum Mechanics • Vorlesungsskript

1	Module name 92503	Numerische Methoden der Halbleiterbauelemente Numerical methods for semiconductor components	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr.-Ing. Friedhard Römer
5	Contents	Grundlagen der numerischen Simulation von quasistationären elektromagnetischen Feldern und elektromagnetischer Wellenausbreitung
6	Learning objectives and skills	Lernziele: • Kenntnisse über verschiedene numerische Methoden zur Lösung der Maxwell'schen Gleichungen im Zeit- und Frequenzbereich • Anwendung der Finite-Differenzen-Zeitbereichsmethode und der Finite-Elemente-Methode zur Lösung elektromagnetischer Feldprobleme
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral Mündliche Prüfung, Dauer 30 min
11	Grading procedure	Oral (100%) 100% der mündlichen Prüfung
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	• Taflov, A., Hagness, S.: Computational Electrodynamics: The Finite-Difference Time-Domain Method. 3rd Ed., Artech House, Norwood, Mass., USA, 2005. • Jin, J.: The Finite Element Method in Electromagnetics. Wiley-IEEE Press, 2007 • Jin, J.-M.: Theory and computation of electromagnetic fields. IEEE Press, Piscataway, New Jersey, USA, 2015. • Vorlesungsskript

1	Module name 92514	Halbleitertechnologie II - Prozess- und Bauelementesimulation (HLT II) Semiconductor technology II - Process and component simulation (HLT II)	2,5 ECTS
2	Courses / lectures	Übung: Übungen zu Halbleitertechnologie II - Prozess- und Bauelemente-Simulation (Termin der Übung wird in der Vorlesung mit den Teilnehmenden der Veranstaltung festgelegt) (1 SWS) Vorlesung: Halbleitertechnologie II - Prozess- und Bauelemente-Simulation (2 SWS)	- 2,5 ECTS
3	Lecturers	Dr. Jürgen Lorenz	

4	Module coordinator	Dr. Jürgen Lorenz
5	Contents	In der Halbleitertechnologie wird eine Vielzahl von Prozessschritten zur Herstellung der Bauelemente verwendet. Aufgabe der Prozesssimulation ist die Voraussage vor allem der Geometrien und Dotierungsverteilungen dieser Bauelemente, woraus dann mithilfe der Bauelementesimulation die elektrischen Eigenschaften abgeleitet werden können. Insgesamt dient die Simulation dem besseren Verständnis der Prozesse und Bauelemente sowie der Reduktion der Entwicklungszeiten und Kosten. In dieser Vorlesung werden die zur Beschreibung der einzelnen Prozessschritte verwendeten physikalischen Modelle dargestellt, wobei sowohl auf die historische Entwicklung als auch auf den aktuellsten Stand der Forschung eingegangen wird. Zur Auswertung dieser Modelle in ein- und mehrdimensionalen Simulationsprogrammen benötigte Algorithmen werden zusammengefasst. Anhand von Anwendungsbeispielen werden spezielle technologische Effekte und ihre simulationsmäßige Beschreibung diskutiert. Des Weiteren werden die Grundlagen der Bauelementesimulation dargestellt. Hierbei wird sowohl auf die gängigen Verfahren zur Simulation des Ladungsträgertransports sowie auf die wichtigsten Modelle für die grundlegenden Halbleitereigenschaften eingegangen. Die Vorlesung schließt mit einer Bestandsaufnahme der in der Industrie verbreitetsten Simulationsprogramme sowie einem Ausblick auf die weitere Entwicklung des Gebiets sowie seiner Anwendungen.
6	Learning objectives and skills	Die Studierenden • gewinnen einen Überblick der Methoden der Geräte-, Prozess- und Bauelementesimulation (Modelle, Algorithmen, Anwendung) • lernen anhand der Prozess- und Bauelementesimulation die Bedeutung und Anwendung der Simulation in den Ingenieurwissenschaften im Allgemeinen kennen • haben damit eine gute Grundlage zur schnellen Einarbeitung als qualifizierter Anwender oder zum Einstieg in die Forschung zur Simulation

7	Prerequisites	Die Vorlesung ist Teil des Zyklus Halbleitertechnologie des LEB und auf diesen abgestimmt. Der vorige Besuch der Vorlesung Halbleitertechnologie I wird empfohlen.
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 92526	Halbleitertechnik VI - Flexible Elektronik (HL VI) Semiconductor technology VI - Flexible electronics (HL VI)	2,5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Dr. Michael Jank	
5	Contents	1. Einführung -Vergleich Elektroniktechnologien, Anwendungen für großflächige und flexible Elektronik • Integrationstechniken 2. Bauelementekonzepte der Dünnschichtelektronik • Dünnschichttransistoren / TFTs • Passive Bauelemente • Ausgewählte Sensoren 3. Materialien und Prozessierung • Beschichtungs- und Drucktechniken • Dünnschichttechnologien (a-Silicium, Polysilicium, Metalloxide, Organik) • Substrat-, Prozess- und Bauelementeoptionen für flexible Anwendungen 4. Mechanische und elektronische Integration • Verbindungstechniken • Drahtlose Schnittstellen 5. Anwendungen • Großflächige Sensoren, Sensormatrizen und Ausleseelektronik • Typen, Aufbau und Ansteuerung von Displays	
6	Learning objectives and skills	Lernende können evidenzbasierte, qualitative und quantitative Urteile zu Sachverhalten anhand von Kriterien anstellen, d.h. technologische Ansätze miteinander vergleichen, Handlungsempfehlungen erstellen und begründen, sowie Lösungsszenarien entwerfen. Lernende können Herangehensweisen zur Vereinfachung komplexer Probleme anwenden, zielorientierte Technologieoptimierung bei gegenseitigen Abhängigkeiten (Kompromissfindung) durchführen sowie Größen und Kerneigenschaften von Technologien erfassen.	
7	Prerequisites	None	
8	Integration in curriculum	no Integration in curriculum available!	
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242	

10	Method of examination	Oral (30 minutes)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 93020	Implementierung von Datenbanksystemen Implementation of database systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Richard Lenz
5	Contents	Die Vorlesung führt ein in den Aufbau und die Architektur von Datenbanksystemen, die Modularisierung und Schichtenbildung mit Abstraktionen verwenden. Schwerpunkt sind deshalb systemtechnische Aspekte von Datenbanksystemen. Die Übungen vertiefen verschiedene Aspekte an Beispielrechnungen und erweitern gelegentlich auch noch den Stoff um einige Facetten (z.b. Mehrattribut-Zugriffspfade). Ausgangspunkt einer Reihe von aufeinander aufbauenden Abstraktionen ist die Speicherung von Daten auf Hintergrundspeichern. Die erste Abstraktion ist die Datei. Dann werden Sätze eingeführt und auf verschiedene Weisen in Blöcken organisiert (sequenziell, mit Direktzugriff, indexsequentiell). Das schließt die Organisation eines Blockpuffers und Zugriffspfade (Indexstrukturen) unterschiedlichen Typs ein. Als zweite große Abstraktion werden Datenmodelle eingeführt und hier insbesondere das relationale. Das ist bereits aus dem Modul "Konzeptionelle Modellierung" bekannt, wird hier aber aus einer ganz anderen Perspektive heraus entwickelt. Der zweite Teil befasst sich mit der Realisierung der Leistungen eines Datenbanksystems unter Verwendung der vorher eingeführten Sätze und Zugriffspfade ("top-down"). Das umfasst die Anfrageverarbeitung und -optimierung, aber auch die Mechanismen zur Protokollierung von Aktionen und zur Wiederherstellung von Datenbankzuständen nach einem Fehler oder Ausfall. Ein laufend vervollständigtes Schichtenmodell fasst abschließend die Aufgaben in einer Architektur für Datenbank-Verwaltungssysteme zusammen. Ziel des Moduls ist es also, ein grundlegendes Verständnis für den Aufbau und die Funktionsweise eines Datenbanksystems zu vermitteln.
6	Learning objectives and skills	Die Studierenden • kennen das Schichtenmodell eines Datenbankverwaltungssystems; • verstehen das Prinzip der Datenunabhängigkeit (Datenabstraktion); • beherrschen das Aufbauprinzip einer Software-Schicht; • unterscheiden die Begriffe "Datenbank", "Datenbanksystem" und "Datenbankverwaltungssystem"; • unterscheiden die Begriffe "Datenmodell" und "Schema"; • zeigen das Konzept der blockorientierten Datei mit ihren Zugriffsoperationen auf; • unterscheiden einen Satz von einem Block; • erklären das Konzept der sequentiellen Satzdatei; • schildern das Prinzip der Wechselfuffertechnik;

		• charakterisieren den Schlüsselzugriff auf Sätze; • stellen Gestreute Speicherung (Hashing) auf der Basis von Blöcken (Buckets) dar; • formulieren die Funktionsweise des Virtuellen Hashings; • fassen die Funktionsweise eines B-Baums zusammen; • unterscheiden die Dienste eines B-Baums von denen des Hashings; • können für eine Folge von Schlüsselwerten einen B-Baum aufbauen; • unterscheiden einen B-Baum von einem B-Stern-Baum (B+-Baum); • veranschaulichen einen Bitmap-Index; • unterscheiden die Primär- und Sekundärorganisation von Sätzen; • zählen Ersetzungsstrategien der Pufferverwaltung auf und vergleichen sie; • benennen die Dienste einer Pufferverwaltung; • erklären die Konzepte "Seite" und "Segment" im Gegensatz zu "Block" und "Datei"; • unterscheiden direkte und indirekte Seitenzuordnung; • interpretieren in Programmiersprachen eingebettete Anfragesprachen und Datenbank-Unterprogrammaufrufe; • charakterisieren Datenbank-Transaktionen; • kennen die Aufrufe zur Definition von Transaktionen; • erläutern die spaltenweise Abspeicherung von Relationen; • diskutieren die algebraische Optimierung von Anfragen; • stellen Planoperatoren eines Datenbanksystems dar; • unterscheiden Planoperatoren für den Verbund; • beschreiben Kostenformeln für die Abschätzung von Anfrageausführungen; • schildern die verschiedenen Anomalien im Mehrbenutzerbetrieb; • beschreiben die Serialisierbarkeit von Transaktionen; • erläutern das Konzept der Sperren in Datenbanksystemen; • unterscheiden physische und logische Konsistenz; • kennen die vier Recovery-Klassen; • erläutern die verschiedenen Arten von Sicherungspunkten.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination with multiple choice (90 minutes)
11	Grading procedure	Written examination with multiple choice (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h

14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	KEMPER, Alfons ; EICKLER, André: Datenbanksysteme : Eine Einführung. 9., aktual. u. erweit. Aufl. München : Oldenbourg, 2013. ISBN 978-3-486-72139-3. Kapitel 7 bis 11 KEMPER, Alfons ; WIMMER, Martin: Übungsbuch Datenbanksysteme. 2., aktual. u. erweit. Aufl. München : Oldenbourg, 2009. ISBN 978-3-486-59001-2. Kapitel 7 bis 11 HEUER, Andreas ; SAAKE, Gunter: Datenbanken : Konzepte und Sprachen. 3., aktual. u. erw. Aufl. Bonn : mitp, 2007. - ISBN 3-8266-1664-2 HÄRDER, Theo ; RAHM, Erhard: Datenbanksysteme : Konzepte und Techniken der Implementierung. Berlin : Springer, 1999 - ISBN 3-540-65040-7 SAAKE, Gunter ; HEUER, Andreas: Datenbanken : Implementierungstechniken. 2., aktual. u. erw. Aufl. Bonn : mitp, 2005. ISBN 3-8266-1438-0

1	Module name 94510	Grundlagen der Messtechnik Fundamentals of metrology	5 ECTS
2	Courses / lectures	Übung: Grundlagen der Messtechnik - Übung (2 SWS) Vorlesung mit Übung: Vorlesung Grundlagen der Messtechnik (4 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr.-Ing. Tino Hausotte	

4	Module coordinator	Prof. Dr.-Ing. Tino Hausotte
5	Contents	Inhalt (Vorlesung): • Allgemeine Grundlagen • Was ist Metrologie: Metrologie und Teilgebiete, Einsatzbereiche, historische Entwicklung des Einheitssystems, SI-Einheitensystem SI-Einheiten (cd, K, kg, m, s, A, mol) Größe, Größenwert Extensive und intensive Größen Messung, Messgröße, Maßeinheit, Messergebnis, Messwert, Gebrauch und korrekte Angabe der Einheiten, Schreibweisen von Größenwerten, Angabe von Einheiten Grundvoraussetzungen für das Messen Rückführung der Einheiten • Messprinzipien, Messmethoden und Messverfahren: Messprinzip, Messmethode, Messverfahren Einteilung der Messmethoden, Ausschlagmessmethode, Differenzmessmethode, Substitutionsmessmethode und Nullabgleichsmethode (Kompensationsmethode) Prinzip eines Messgerätes, direkte und indirekte Messmethoden Kennlinie und Kennlinienarten, analoge und digitale Messmethoden, kontinuierliche und diskontinuierliche Messung, Auflösung, Empfindlichkeit, Messbereich absolute und inkrementelle Messmethoden • Statistik Auswertung von Messreihen: Berechnung eines Messergebnisses anhand von Messreihen Grundbegriffe der deskriptiven Statistik Darstellung und Interpretation von Messwertverteilungen (Histogramme) Häufigkeit (absolute, relative, kumulierte, relative kumulierte) Berechnung und Interpretation grundlegender Parameter: Lage (Mittelwert, Median, Modus), Streuung (Spannweite, Varianz, Standardabweichung, Variationskoeffizient), Form (Schiefe, Kurtosis bzw. Exzess) Grundbegriffe der Stochastik, Wahrscheinlichkeiten, Verteilungen (Rechteck-, U- und Normalverteilung), Zentraler Grenzwertsatz, statistische Momente Grundbegriffe der analytischen Statistik, statistische Tests und statistische Schätzverfahren Korrelation und Regression • Messabweichungen und Messunsicherheit: Messwert, wahrer Wert, Ringvergleich, vereinbarter Wert Einflüsse auf die Messung (Ishikawa-Diagramm) Messabweichung (absolute, relative, systematische, zufällige) Umgang mit Messabweichungen, Korrektur bekannter systematischer Messabweichungen Kalibrierung, Verifizierung, Eichung

Messpräzision, Messgenauigkeit, Messrichtigkeit
Wiederholbedingungen/-präzision, Vergleichsbedingungen/-präzision, Erweiterte Vergleichsbedingungen/-präzision
Fehlerfortpflanzungsgesetz (altes Konzept), Messunsicherheit, Eigenunsicherheit, Übersicht über Standardverfahren des GUM (Messunsicherheit), korrekte Angabe eines Messergebnisses

- Messgrößen des SI-Einheitensystems
- Messen elektrischer Größen und digitale Messtechnik: SI-Basiseinheit Ampere, Widerstands- und Spannungsnormale, Messung von Strom und Spannung, Lorentzkraft, Drehspulmesswerk, Bereichsanpassung Widerstandsmessung, strom- und spannungsrichtige Messung, Wheatstonesche Brückenschaltung (Viertel-, Halb- und Vollbrücke, Differenzmethode und Kompensationsmethode) Charakteristische Werte sinusförmiger Wechselgrößen, Dreheisenmesswerk, Wechselspannungsbrücke Messsignale, dynamische Kennfunktionen und Kennwerte, Übertragungsfunktionen (Frequenzgänge) Digitalisierungskette, Zeit- und Werdiskretisierung, Alias-Effekte, Shannons Abtasttheorem, Filter, Operationsverstärker (Invertierender Verstärker, Nichtinvertierender Verstärker, Impedanzwandler, invertierender Addierer, Differenzverstärker, Integrierer, Differenzierer, Instrumentenverstärker), Abtast-Halte-Glied, Analog-Digital-Wandlung, Abweichungen bei der Analog-Digital-Wandlung Universelle Messgeräte (Digitalmultimeter, analoge und digitale Oszilloskope)
- Messen optischer Größen: Licht und Eigenschaften des Lichtes Empfindlichkeitsspektrum des Auges Radiometrie und Photometrie SI-Basiseinheit Candela (cd, Lichtstärke) Strahlungsfluss, radiometrisches (fotometrisches) Grundgesetz, photometrische und radiometrische Größen Strahlungsgesetze Fotodetektoren (Fotowiderstände, Fotodioden, Betriebsarten, Bauformen, CCD- und CMOS-Sensoren)
- Messen von Temperaturen: Temperatur, SI-Basiseinheit Kelvin, Definition, Wärmeübertragung (Wärmeleitung, Konvektion, Wärmestrahlung) Thermodynamische Temperatur Primäre und sekundäre Temperaturmessverfahren, praktische Temperaturskalen, Fixpunkte (Tripelpunkte, Erstarrungspunkte), Fixpunktzellen, klassische Temperaturskalen, internationale Temperaturskala (ITS-90) Berührungsthermometer, thermische Messabweichungen, thermische Ausdehnung, Gasthermometer, Flüssigkeitsglasthermometer, Bimetall-Thermometer, Metall-Widerstandsthermometer (Kennlinie, Genauigkeit, Bauformen, Messschaltungen), Thermoelemente (Seebeck-Effekt, Bauformen, Ausgleichsleitungen,

Messschaltungen) Strahlungsthermometer (Prinzip, Strahlungsgesetze, Pyrometer, Messabweichungen)

- Zeit und Frequenz: SI Basiseinheit Sekunde, Zeitmessung (Aufgaben, Historie, mechanische Uhren, Quarzuhren, Atomuhr) Darstellung der Zeit Verbreitung der Zeitskala UTC Globales Positionssystem (GPS) Frequenz- und Phasenwinkelmessung
- Längenmesstechnik: SI Basiseinheit Meter Messschieber, Abbesches Komparatorprinzip, Bügelmessschraube, Abweichungen 1.- und 2.-Ordnung Längenmessung mit Linearencodern (Bewegungsrichtung, Ausgangssignale, Differenzsignale, Demodulation) Absolutkodierung (V-Scannen und Gray Code) Interferometrie, Michelson-Interferometer, transversale elektromagnetische Wellen, Grundlagen der Interferenz, destruktive und konstruktive Interferenz, Homodynprinzip, Heterodynprinzip, Interferenz am Homodyninterferometer, Demodulation am Homodyn- und Heterodyninterferometer, Einfluss Luftbrechzahl, Realisierung der Meterdefinition, Reflektoren und Aufbau von Interferometern, induktive Längenmessung, kapazitive Längenmessung, Laufzeitmessung
- Masse, Kraft und Drehmoment: SI Basiseinheit Kilogramm, Definition Masse, Kraft und Drehmoment Massenormale (Vergleiche, Bauformen und Abweichungsgrenzen), Prinzip der Masseableitung, Stabilität der Einheit und Neudefinition Messprinzipien von Waagen, Einflussgrößen bei Massebestimmung (lokale Erdbeschleunigung, Luftauftrieb), Balkenwaage (unterschälige Waagen, Empfindlichkeit, Bauformen, oberchalige Waagen, Ecklastabhängigkeit), Federwaage, DMS, Verformungskörper, DMS-Waage, EMK-Waage, Massekomparatoren Drehmomentmessung (Reaktions- und Aktionsdrehmoment)
- Teilgebiete der industriellen Messtechnik
- Prozessmesstechnik: Messgrößen der Prozessmesstechnik Definition des Druckes, Druckarten (Absolutdruck, Überdruck, Differenzdruck) Druckwaage (Kolbenmanometer), U-Rohrmanometer und -Barometer, Rohrfedermanometer, Plattenfedermanometer Drucksensoren (mit DMS, piezoresistiv, kapazitiv, piezoelektrisch) Durchflussmessung (Volumenstrom und Massestrom, Strömung von Fluiden) volumetrische Verfahren, Wirkdruckverfahren, magnetisch-induktive Durchflussmessung, Ultraschall-Durchflussmessung Massedurchflussmessung (Coriolis, thermisch)
- Fertigungsmesstechnik: Aufgaben, Methoden, Ziele und Bereiche der Fertigungsmesstechnik Gestaltparameter von Werkstücken (Mikro- und Makrogestalt), Geometrische Produktspezifikation (GPS), Gestaltabweichungsarten Geräte und Hilfsmittel der Fertigungsmesstechnik, Gegenüberstellung klassische Fertigungsmesstechnik

und Koordinatenmesstechnik, Auswertung Bauarten und Grundstruktur von Koordinatenmessgeräten Vorgehensweise bei Messen mit einem Koordinatenmessgerät

Inhalt (Übung):

- Grundlagen der Elektrotechnik (Wiederholung von Grundlagen)
- Statistik Auswertung von Messreihen (Histogramme, Hypothesentest, Konfidenzintervalle, statistischen Maßzahlen)
- Korrelation und Regression (Korrelationskoeffizient, Fehlerfortpflanzung, Residuenanalyse)
- Messabweichungen, Einführung in die Messunsicherheitsberechnung (Kompensation systematischer Abweichungen, Messunsicherheitsanalyse einer einfachen Messung)
- Elektrische Größen, Messelektronik und Analog-Digital-Umsetzung (Abweichungsberechnung bei der Strommessung, Anpassungsnetzwerk für ein Drehspulinstrument, Bereichsanpassung mit einem Operationsverstärker)
- Anwendung der Wheatstoneschen Brückenschaltung bei Messungen mit Dehnungsmessstreifen
- Messungen mit Fotodioden bei unterschiedlichen Betriebsarten
- Temperaturmesstechnik (Aufgaben zu Metall-Widerstandsthermometern und Pyrometern)
- Längenmesstechnik (Abbesche Prinzip, Induktivität eines Eisenkerns mit Luftspalt, Foliendickenmessung mittels einer kapazitiven Messeinrichtung)
- Messen von Kraft und Masse (Massewirkung, Balkenwaage, Federwaage, piezoelektrischer Kraftsensor)
- Prozessmesstechnik (Druck- und Durchflussmessung, U-Rohrmanometer, Corioliskraftmessung, Ultraschallmessverfahren, Turbinenzähler)
- Fertigungsmesstechnik (Standardgeometrieelemente, Angabe von Toleranzen, Prüfen von Rundheitsabweichungen mit Hilfe eines Feinzeigers)

Contents:

- General basics
- What is metrology: Metrology and branches, application fields, historical development of the unit system, SI unit system Definitions of SI units (cd, K, kg, m, s, A, mol) Quantity, quantity value Extensive and intensive quantities Measurement, measurand, measurement unit, measurement result, measured quantity value Correct use and notation of units and of quantity values Basic requirements for the measurement Traceability
- Principles, methods and procedures of measurement: Principles, methods and procedures of measurement Classification of measurement methods, deflection, differential, substitution and compensation measurement methods

Principle of a measuring instrument, direct and indirect measurement methods Characteristic curve, types of characteristic curves, analogue and digital measurement methods, continuous and discontinuous measurement, resolution, sensitivity, measuring interval Absolute and incremental measurement methods

- Statistics Evaluation of measurements series: Calculation of a measurement result based on measurement series Basic terms of descriptive statistics Presentation and interpretation of measured value distributions (histograms) Frequency (absolute, relative, cumulative, relative cumulative) Calculation and interpretation of basic parameters: location (mean, median, mode), dispersion (range, variance, standard deviation, coefficient of variation), shape (skewness, excess, kurtosis) Basic terms of stochastics, probabilities, distributions (rectangle, U and normal distribution), central limit theorem, statistical moments Basic terms of analytical statistics, statistical tests and statistical estimation methods Correlation and regression
- Measurement errors and measurement uncertainty: Measured value, true value, key comparison, conventional quantity value Influences on the measurement (Ishikawa diagram) Measurement error (absolute, relative, systematic, random) Handling of errors, correction of known systematic measurement errors Calibration, verification, legal verification Measurement precision, accuracy and trueness Repeatability conditions and repeatability, intermediate precision condition and measurement precision, reproducibility condition of measurement and reproducibility Error propagation law (old concept), measurement uncertainty, definitional uncertainty, overview of standard method of the GUM (measurement uncertainty), correct specification of a measurement result
- Mesurands of the SI system of units
- Measurement of electrical quantities: SI base unit Ampere, resistance and voltage standards, measurement of current and voltage, Lorentz force, moving coil instrument, range adjustment Resistance measurement, current and voltage correct measurement, Wheatstone bridge circuit (quarter, half and full bridge, differential method and compensation method) Characteristic values of sinusoidal alternating quantities, moving iron instrument, alternating voltage bridge Measuring signals, dynamic characteristic functions and characteristics, transfer functions (frequency responses) Digitalisation chain, time and value discretization, aliasing, Shannons sampling theorem, filter, operational amplifier (inverting amplifier, non-inverting amplifier, impedance converter, inverting summing amplifier, differential amplifier, integrating amplifier, differentiating amplifier, instrumentation amplifier), sample-and-hold device, analogue-digital conversion, errors of

analogue-to-digital conversion Universal measuring devices (digital multimeter, analogue and digital oscilloscopes)

- Measurement of optical quantities: Light and properties of light Sensitivity spectra of the eye Radiometry and photometry SI base unit candela (cd, luminous intensity) Radiant flux, radiometric (photometric) fundamental law, photometric and radiometric quantities Radiation laws Photo detectors (photo resistors, photo diodes, modes of operation, designs, CCD and CMOS sensors)
- Measurement of temperatures: Temperature, SI base unit Kelvin, definition, heat transfer (conduction, convection, radiation) Thermodynamic temperature Primary and secondary temperature measurement methods, practical temperature scales, fixpoints (triple points, freezing points), fixpoint cells, classical temperature scales, International Temperature Scale (ITS-90) Contact thermometers, thermal measurement errors, thermal expansion, gas thermometer, liquid thermometer, bimetal thermometer, metal resistance thermometers (characteristic curve, accuracy, designs, circuits), thermocouples (Seebeck effect, designs, extension wires, measurement circuits) Radiation thermometer (principle, radiation laws, pyrometers, measurement errors)
- Time and frequency: SI base unit second, time measurement (tasks, history, mechanical clocks, quartz clock, atomic clock) Representation of time Propagation of UTC Global Positioning System (GPS) Frequency and phase angle measurement
- Length: SI base unit metre Calliper, Abbe comparator principle, micrometer, errors 1st and 2nd order Length measurement with linear encoders (motion direction, output signals, differential signals, demodulation) Absolute coding (V-Scan and Gray code) Interferometry, Michelson interferometer, transversal electromagnetic waves, basics of interference, destructive and constructive interference, homodyne principle, heterodyne principle, interference on homodyne interferometer, demodulation at homodyne and heterodyne interferometer, influence of air refractive index, realisation of the metre definition, reflectors and assembly of interferometers, inductive length measurement, capacitive length measurement, time of flight measurement
- Mass, force and torque: SI base unit kilogram, definition of mass, force and torque Mass standards (comparisons, types, deviation limits), principle of mass dissemination, stability of the unit and redefinition Measurement principles of weighing, influences for mass determination (local gravitational acceleration, air buoyancy), beam balance (hanging pan balances, sensitivity, types, top pan balances, corner load sensitivity), spring balance, DMS, deformation elements, DMS balance, EMC balance, mass comparators Measurement of torque (reactive and active)

		• Branches of industrial metrology • Process measurement technology: Quantities of process measurement technology Definition of pressure, pressure types (absolute pressure, overpressure, differential pressure) Deadweight tester (piston manometer), U-tube manometer and barometer, bourdon tube gauge, diaphragm pressure gauge Pressure sensors (with DMS, piezoresistive, capacitive, piezoelectric) Flow measurement (volume flow and mass flow, flow of fluids) Volumetric method, differential pressure method, magneto-inductive flowmeter, ultrasonic flow measurement Mass flow rate measurement (Coriolis, thermal) • Manufacturing metrology: Tasks, methods, objectives and branches of manufacturing metrology Form parameters of workpieces (micro-and macro-shape), geometrical product specification (GPS), geometrical tolerances Comparison of classical manufacturing metrology and coordinate metrology, evaluation Designs and basic structure of coordinate measuring machines Procedure for measuring with a coordinate measuring machine
6	Learning objectives and skills	*Wissen* • Die Studierenden kennen grundlegende statistische Methoden zur Beurteilung von Messergebnissen und Ermittlung von Messunsicherheiten. • Die Studierenden kennen grundlegende Messverfahren zur Erfassung der Messgrößen aller SI-Einheiten. • Die Studierenden kennen das Basiswissen zu Grundlagen der Messtechnik und messtechnischen Tätigkeiten. • Die Studierenden haben Grundkenntnisse zur methodisch-operativen Herangehensweise an Aufgaben des Messens statischer Größen, zum Lösen einfacher Messaufgaben und zum Ermitteln von Messergebnissen aus Messwerten. *Verstehen* • Die Studierenden können die Eigenschaften von Messeinrichtungen und Messprozessen beschreiben. • Die Studierenden können das Internationale Einheitensystem und die Rückführung von Messergebnissen beschreiben. *Anwenden* • Die Studierenden können einfache Messungen statischer Größen durchführen. • Die Studierenden können Messunsicherheiten komplexer Messeinrichtungen bei gegebenen Eingangsgrößen berechnen. *Evaluieren (Beurteilen)* • ◦ The students know basic statistical methods for the evaluation of measurement results and the determination of measurement uncertainties. ◦ The students know basic measuring methods for the record of measured values for all SI units.

		◦ The students have basic knowledge of fundamentals of metrology and metrology activities. ◦ The students have fundamental knowledge for methodological and operational approach to measuring tasks of static measurement types, to solve basic measurement tasks and to establishing measurement results from measurement values. ◦ The students are able to describe the characteristics of measuring instruments and measurement processes. ◦ The students are able to describe the international system of units (SI) and the traceability of measurement results ◦ The students are able to run basic measurements of static measurands. *Evaluating* The students are able to evaluate measuring systems, measurement processes and measurement results. Students are able to calculate the measurement uncertainty of complex measuring systems for given input variables.
7	Prerequisites	None
8	Integration in curriculum	semester: 5
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (60 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german english
16	Bibliography	International Vocabulary of Metrology Basic and General Concepts and Associated Terms, VIM, 3rd edition, JCGM 200:2008, http://www.bipm.org/en/publications/guides/vim.html DIN e.V. (Hrsg.): Internationales Wörterbuch der Metrologie Grundlegende und allgemeine Begriffe und zugeordnete Benennungen (VIM) ISO/IEC-Leitfaden 99:2007. Korrigierte Fassung 2012, Beuth Verlag GmbH, 4. Auflage 2012 Hoffmann, Jörg: Handbuch der Messtechnik. 4. Auflage, Carl Hanser Verlag München, 2012 ISBN 978-3-446-42736-5 Lerch, Reinhard: Elektrische Messtechnik. 6. Auflage, Springer-Verlag Berlin Heidelberg, 2012 ISBN 978-3-642-22608-3 Richter, Werner: Elektrische Meßtechnik. 3. Auflage, Verlag Technik Berlin, 1994 - ISBN 3-341-01106-4

	Kohlrausch, Friedrich: Praktische Physik : zum Gebrauch für Unterricht, Forschung und Technik. Band 1-3, 24. Auflage, Teubner Verlag, 1996 ISBN 3-519-23001-1, 3-519-23002-X, 3-519-23000-3

	H. Czichos (Hrsg.): Das Ingenieurwissen Gebundene. 7. Auflage, Springer Verlag, 2012, ISBN 978-3-642-22849-0.

	Ernst, Alfons: Digitale Längen- und Winkelmesstechnik. 4. Auflage, Verlag Moderne Industrie, 2001 ISBN 3-478-93264-5

	Pfeifer, Tilo: Fertigungsmeßtechnik. R. Oldenbourg Verlag München Wien, 1998 ISBN 3-486-24219-9

	Keferstein, Claus P.: Fertigungsmesstechnik. 7. Auflage, Vieweg +Teubner Verlag, 2011 ISBN 978-3-8348-0692-5

	Warnecke, H.-J.; Dutschke, W.: Fertigungsmeßtechnik. Springer-Verlag Berlin Heidelberg New York Tokyo, 1984 ISBN 3-540-11784-9

1	Module name 94946	Industrie 4.0 - Anwendungsszenarien in Produktion und Service Industry 4.0 - Application scenarios in production and service	2,5 ECTS
2	Courses / lectures	Vorlesung: Industrie 4.0 - Anwendungsszenarien in Produktion und Service (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Ulrich Löwen Tobias Reichenstein	

4	Module coordinator	Prof. Dr.-Ing. Jörg Franke
5	Contents	Die IT-Durchdringung in der produzierenden Industrie nimmt rasant zu. Der nutzenstiftende Einsatz von IT bei der Gestaltung von Wertschöpfungsprozessen hat für Deutschland eine zentrale strategische Bedeutung. Diese Trends werden unter Begriffen wie Industrie 4.0" und Industrial Internet" bzw. Internet of Things" weltweit diskutiert. Dabei treffen doch recht unterschiedliche Sichtweisen aufeinander. In der Vorlesung werden diese Trends und Visionen anhand von ausgewählten Anwendungsszenarien erläutert. Außerdem werden die dafür zum Verständnis notwendigen Grundlagen erklärt. Ziele: • Bewusstseins-schärfung bezüglich der Auswirkungen der Digitalisierung auf die produzierende Industrie • Verständnis von Geschäftstreibern, technischen Möglichkeiten und deren Wechselwirkungen in der produzierenden Industrie • Vermittlung Branchen- und Domänen-übergreifender Prozesse und Methoden in der produzierenden Industrie
6	Learning objectives and skills	Den Studierenden sollen die Auswirkungen der Digitalisierung auf die produzierende Industrie verdeutlicht und dadurch ein Bewusstsein für diese Entwicklungen geschaffen werden. Zusätzlich soll ein Verständnis für Geschäftstreiber, technische Möglichkeiten und deren Wechselwirkungen in der produzierenden Industrie sowie branchen- und domänenübergreifender Prozesse und Methoden vermittelt werden. Die Vorlesung ist auf Basis der folgenden Leitlinien aufgebaut: • Methodische und konsequente Trennung der Diskussion von Problemperspektive, konzeptioneller Lösungsperspektive und technischer Umsetzungsperspektive • Umfassendes Gesamtverständnis bezüglich der oft sehr vielschichtigen wirtschaftlichen und technischen Zusammenhänge (zu Lasten eines tiefen technischen Diskussions) • Betonung des für einen Anwender gestifteten (geschäftlichen) Nutzens und der möglichen Alleinstellungsmerkmale für einen Standort Deutschland Die Studierenden sind nach Besuch der Lehrveranstaltung in der Lage: • die kontroversen und vielschichtigen Diskussionen im Umfeld der Digitalisierung in der Produzierenden Industrie in einen konsistenten Gesamtkontext einzuordnen

		• anhand repräsentativer Beispiele den Unterschied zu verstehen zwischen dem aktuellen Stand der Technik und Forschung sowie den durch Industrie 4.0 postulierten Innovationshypothesen • aufgrund der vermittelten Beispiele und Methoden durch eine Hinterfragung von Zielen und des wirtschaftlichen Nutzens die oft stark emotional geführten Diskussionen im Kontext von Industrie 4.0 zu versachlichen Das im Rahmen dieser Lehrveranstaltung vermittelte Wissen ist in allen Bereichen der industriellen Branchen, so z. B. im Automobilbau, der Informatik und Wirtschaftsinformatik, der Elektrotechnik und Medizintechnik und dem Maschinen- und Anlagenbau erforderlich.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (60 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 35 h Independent study: 40 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 94963	Industrielle Testanwendungen für Integrierte Schaltungen und Systeme Industrial test applications for integrated circuits and systems	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr. Heinz Mattes Peter Meisel
5	Contents	Die Vorlesung behandelt die Grundlagen des Tests von integrierten Schaltungen und deren industrielle Anwendung. *Produktionstest im industriellen Umfeld* *Fallbeispiele an aktuellen Produkten* • Microcontroller für Automotive Anwendungen • RF-Module für Mobilfunkanwendung • Entry-Phone Anwendungen • Feature-Phone Anwendungen * Built-In-Self-Test* Im Rahmen der LV wird eine Exkursion zum Halbleiterhersteller Infineon in München angeboten.
6	Learning objectives and skills	Verstehen • Die Studierenden kennen die Auswirkung und Einflüsse vom Test auf die Produktion von integrierten Schaltungen • Die Studierenden vergleichen Testmethoden an Hand von Fallbeispielen bei aktuellen Produkten (Automobil, Mobilfunk) • Die Studierenden veranschaulichen Methoden zur Testsignalerzeugung Analysieren und Erschaffen • Die Studierenden validieren die verschiedenen Testmethoden unter Berücksichtigung von Kostenaspekten und der Montagetechnik • Die Studierenden analysieren und entwerfen ressourcenschonende Algorithmen und beurteilen Built-in-Self-Test Lösungen aus der aktuellen Fachliteratur
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable Mündliche Prüfung Dauer: 30 Minuten
11	Grading procedure	Variable (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 45 h

		Independent study: 30 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 94965	Seminar zu Fragen des Entwurfs Sicherheitskritischer Schaltungen Seminar on safety critical circuit design issues	2,5 ECTS
2	Courses / lectures	Hauptseminar: Seminar zu Fragen des Entwurfs Sicherheitskritischer Schaltungen (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Sebastian Sattler	

4	Module coordinator	Prof. Dr.-Ing. Sebastian Sattler
5	Contents	Inhalt des Seminars sind wissenschaftlich und technologisch aktuelle Themen der Lehr- und Forschungsgebiete des LZS: • Alle Ebenen des Entwurfs Sicherheitskritischer Schaltungen oder Systeme • Modellierung, Simulation und Test Sicherheitskritischer Schaltungen • Algorithmen, Methoden und Werkzeuge für den rechnergestützten Entwurf • Anwendungen von Sicherheitskritischen Schaltungen und Mikrosystemen
6	Learning objectives and skills	Die Studierenden arbeiten an den folgenden Fachkompetenzen: Fachkompetenz Evaluieren (Beurteilen) • in der Lage sein, ausgewählte Themen aus dem Themenfeld Sicherheitskritischer Schaltungen und nach entsprechender Literaturrecherche zu verstehen, die Sachverhalte zu beurteilen, zu erläutern und diese in einem Vortrag zu präsentieren Lern- bzw. Methodenkompetenz • eine Literaturrecherche zum Thema durchführen, wissenschaftliche Inhalte übersichtlich darstellen, die Materialsammlung analysieren und eine angemessene Stoffauswahl erstellen Selbstkompetenz • den Sachverhalt zum Seminarthema in einem anschaulichen Vortrag präsentieren und in der Lage sein, technische Sachverhalte zu diskutieren
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable Seminarleistung: Ausarbeitung mit Umfang von 10 bis 20 Seiten Vortrag über 30 Minuten mit anschließender Diskussion von 15 Minuten
11	Grading procedure	Variable (100%) Gewichtung: Ausarbeitung 70%, Vortrag 30%

12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 94966	Radarfernerkundung mit Satelliten Radar remote sensing with satellites	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Gerhard Krieger
5	Contents	Radarsatelliten ermöglichen die hochaufgelöste Abbildung der Erde unabhängig von Wetter und Tageslicht. Durch die Kombination von Radarbildern können zusätzlich kleinste Veränderungen auf der Erdoberfläche millimetergenau aus dem Weltall vermessen werden. Die gewonnenen Daten werden für eine Vielzahl von kommerziellen, wissenschaftlichen und hoheitlichen Anwendungen genutzt. Beispiele sind die Koordination von Hilfseinsätzen bei Katastrophen, die Erstellung hochgenauer topographischer Karten oder die Vermessung des durch den Klimawandel induzierten Abschmelzens der Gletscher.
6	Learning objectives and skills	Fachkompetenz Verstehen Lernende können Wirkprinzipien der Erdfernerkundung mit Satelliten darstellen. Anwenden Lernende können verschiedene Methoden der Erdfernerkundung mit Satelliten unterscheiden und vergleichen. Analysieren Lernende können Erfassungsmethoden diskutieren und geeignete Verfahren für Fragestellungen der Erdfernerkundung auswählen. Erschaffen Lernende können mit dem vermittelten Wissen grundlegende Sensoriken für Satellitensysteme konzipieren.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 94969	Elektrische Energiespeichersysteme Power storage systems	2,5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Thomas Eberle
5	Contents	• Einführung in elektrische Energiespeichersysteme und deren Anwendung hinsichtlich Betriebsweise und Belastungsformen in mobilen und stationären Anwendungen. • Grundlagen zu elektrochemischen und physikalischen Energiespeichern sowie der notwendigen Elektronik zur Überwachung (z.B. Batteriemanagement (BMS)) und Anbindung an Erzeuger und Verbraucher (z.B. Leistungselektronik). • Betrachtung von Batteriesystemen (Pb, NiCd, NiMH, NaNiCl₂, Lilo), Brennstoffzellen, Schwungmassenspeichern, Kondensatoren und thermischen Speichern. • Grundlagen zur analytischen Auslegung von Speichersystemen für mobile und stationäre Anwendungen hinsichtlich Energieinhalt, Lade-/Entladeleistung, Verlustleistung und Lebensdauer • Sicherheitsaspekte beim Einsatz von Energiespeichern
6	Learning objectives and skills	Es werden die Grundlagen für die Auswahl und den Einsatz von elektrischen Energiespeichern vermittelt. Dazu werden die am weitesten verbreiteten elektrochemischen Energiespeicher vorgestellt und ihre spezifischen Eigenschaften diskutiert. Daneben werden auch Speichersysteme auf Basis von Kondensatoren, Schwungmassenspeichern und Wasserstoffbasierten Brennstoffzellen behandelt. Dazu werden die grundlegenden elektrischen Eigenschaften und das Verhalten der Systeme beschrieben. Für den Einsatz in unterschiedlichen Anwendungen lernen die Studierenden die notwendigen Anforderungen zu spezifizieren, die Datenblattangaben zu interpretieren und Speichersysteme auszulegen.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable
11	Grading procedure	Variable (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester

15	Teaching and examination language	german
16	Bibliography	Moderne Akkumulatoren richtig einsetzen, 2 . überarbeitete Auflage, Andreas Jossen, Wolfgan Weydanz, ISBN: 978-3-736-99945-9 Handbuch Lithium-Ionen-Batterien, Herausgeber: Korthauer, Reiner (Hrsg.) , ISBN 978-3-642-30653-2

1	Module name 94971	Elektrische Energiespeichersysteme Power storage systems	5 ECTS
2	Courses / lectures	Vorlesung: Elektrische Energiespeichersysteme (3 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Martin März Dr.-Ing. Bernd Eckardt	

4	Module coordinator	Thomas Eberle
5	Contents	Introduction to electric energy storage systems and their applications regarding the mode of operation and load scenarios in mobile and stationary applications Basics on electrochemical and physical energy storage systems as well as the used electronics for measuring (e.g. battery management system (BMS)) and connecting the storage to the source or load (e.g. power electronic). Different electrochemical storage systems (Pb, NiCd, NiMH, NaNiCl₂, Lilo), fuel cells, flywheels, capacitors and thermal storages Basics on analytic calculations of necessary ratings for mobile and stationary applications according to capacity, charge and discharge power, losses and lifetime Safety aspects using energy storage systems
6	Learning objectives and skills	Students who participate in this course get basic knowledge on the use and selection of different electric energy storage systems. Therefore the most common used electrochemical storage systems are presented and the specific properties are discussed. Further on storage solutions based on capacitors, flywheels and fuel cells are covered. The basic electric performance and the system behavior is described. For different applications the students learn to specify the necessary requirements, to work with available datasheets and to configure electric storage systems.
7	Prerequisites	Prerequisites: To succeed in this course, students will need basic knowledge in chemistry and electronics.
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable (90 minutes) schriftliche Klausur (90 min.)
11	Grading procedure	Variable (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german

16	Bibliography	Moderne Akkumulatoren richtig einsetzen, 2 . überarbeitete Auflage, Andreas Jossen, Wolfgan Weydanz, ISBN: 978-3-736-99945-9 Handbuch Lithium-Ionen-Batterien, Herausgeber: Korthauer, Reiner (Hrsg.) , ISBN 978-3-642-30653-2

1	Module name 95801	Medizintechnik I (Biomaterialien) Medical engineering I (biomaterials)	5 ECTS
2	Courses / lectures	Übung: Übungen zu Medizintechnik I (Biomaterialien) (2 SWS) Vorlesung: Medical Engineering 1 (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Dr. Julia Will	

4	Module coordinator	Prof. Dr.-Ing. Aldo Boccaccini
5	Contents	• Biomaterialien: Definition • Bioabbaubare Polymere, bioaktive Keramiken und biokompatible Metalle • Biomaterialien für Dauerimplantate • Orthopädische Beschichtungen • Biomaterialien fuer Tissue Engineering: Soft- und Hardgewebe • Einführung in die Scaffold-Technologie • Einführung in Scaffold-Charakterisierung • Biomaterialien für Drug Delivery
6	Learning objectives and skills	Die Studierenden • kennen die Vielfalt verschiedener Werkstoffe, die bei der Herstellung von Biomaterialien und als Werkstoffe in der Medizin Anwendung finden. • können die notwendigen Eigenschaften und Herstellungsmethoden von Biomaterialien für Dauerimplantate, Tissue Engineering und Drug Delivery benennen und differenzieren. • können Biomaterialien für verschiedene Anwendungen auswählen.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Klausur, 90 min.
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german english
16	Bibliography	• Wintermantel, Suk-Woo: Medizintechnik; Berlin, 5. Auflage, 2009 • Hench, Jones (eds.): Biomaterials, artifical organs und tissue engineering; Oxford, 2005

	• B.D. Ratner, W.S. Hoffman, F.J. Schoen, J.E. Lemons, Biomaterials Science: An Introduction to Materials in Medicine, Elsevier, Amsterdam, (2004)

1	Module name 96000	Antennen Antennae	5 ECTS
2	Courses / lectures	Vorlesung: Antennen (2 SWS) Übung: Antennen Übung (2 SWS)	5 ECTS -
3	Lecturers	Dr.-Ing. Jan Steffen Schür Johannes Fleischmann	

4	Module coordinator	Prof. Dr.-Ing. Martin Vossiek
5	Contents	• Einführung (Abstrahlung, Antennentypen, Anwendungsaspekte) • Grundlagen (Ebene Wellen, Polarisierung, Hertzscher Dipol, Kenngrößen) • Linearantennen (Dipole, Linienquellen) • Array-Antennen (Arrayfaktor, Verkopplung, Belegungsfunktionen) • Strahlschwenkung (Phasengesteuerte Arrays, frequenzgesteuerte Arrays) • Resonante Antennen (Babinet's Prinzip, Schlitzantennen, Patch-Antennen) • Aperturstrahler (Huygens Prinzip, Hornstrahler, Reflektorantennen) • Linsenantennen (Strahlenoptik, Linsentypen, künstliche Dielektrika) • Numerische Berechnungsverfahren (FDTD-Methode, Simulationsbeispiele) • Breitbandantennen (Winkelprinzip, Spiralantennen, Log.-Per. Antennen, Baluns) • Systemanwendungen von Antennen (Diversity, Mobilfunk, Radarsysteme) • Antennen-Messtechnik
6	Learning objectives and skills	Die Studierenden • lernen analytische und numerische Berechnungsmethoden für Antennen und Funkfelder kennen und anwenden. • erwerben fundierte Kenntnisse über klassische und spezielle Antennenbauformen und deren Charakteristiken für unterschiedliche Anwendungsgebiete im Kommunikations- und Radarbereich. • sind in der Lage, die Kenngrößen und die hochfrequenten Eigenschaften von einfachen Antennen, Gruppenantennen und Funkfeldern zu berechnen, darzustellen und zu bewerten.
7	Prerequisites	Empfohlene Voraussetzungen: • Passive Bauelemente und deren HF-Verhalten • Elektromagnetische Felder I • Hochfrequenztechnik
8	Integration in curriculum	semester: 6
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242

10	Method of examination	Written examination (90 minutes) Prüfungsform: schriftlich (90 Minuten)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	• Kraus, Marhefka: Antennas for All Applications, International Edition, McGraw-Hill, Boston, 3rd Edition, 2002. • Balanis: Antenna Theory, Analysis and Design, John Wiley & Sons, New York, 2nd Edition, 1997.

1	Module name 96010	Architekturen der digitalen Signalverarbeitung Architectures for digital signal processing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Georg Fischer
5	Contents	Inhalt: • Basis-Algorithmen der Signalverarbeitung (FFT, Fensterung, Digitale FIR- und IIR-Filter) • Nichtideale Effekte bei Digitalfiltern (Quantisierung der Filterkoeffizienten, Quantisierte Arithmetik) • CORDIC-Architekturen • Architekturen für Multiraten-systeme (Abtastratenumsetzer) • Architekturen digitaler Signalgeneratoren • Maßnahmen zur Leistungssteigerung (Pipelining) • Architekturen digitaler Signalprozessoren • Anwendungen Content: • Basic algorithms of signal processing (FFT, windowing, digital FIR and IIR-filters) • Non-idealities of digital filters (quantization of filter coefficients, fixed-point arithmetic) • CORDIC-architectures • Architectures of systems with multiple sampling rates (conversion between different sampling rates) • Digital signal generation • Measures of performance improvement (pipelining) • Architecture of digital signal processors • Applications
6	Learning objectives and skills	Die Studierenden erlangen Grundlagenkenntnisse der Signaltheorie und können zeit- und wertkontinuierliche sowie zeit- und wertdiskrete Signale im Zeit- und Frequenzbereich definieren und erklären Die Studierenden sind in der Lage, ein klassisches Echtzeitsystem zur digitalen Signalverarbeitung konzeptionieren und die Einzelkomponenten nach den Anforderungen zu dimensionieren Die Studierenden erlangen einen Überblick über Vor- und Nachteile analoger sowie digitaler Signalverarbeitung Die Studierenden verstehen die Theorie der Fourier-Transformation und sind in der Lage, die Vorteile der Fast-Fourier-Transformation in der digitalen Signalverarbeitung zu verstehen und anzuwenden Die Studierenden können digitale Filter dimensionieren und beurteilen ===Englisch=== Students

		• can obtain fundamentals of signal theory and can define as well time-continuous and value-continuous as time-discrete and value-discrete signals in time and frequency domain • can construct a realtime digital signal processing system and dimension its components according requirements • can review pros and cons of analogue versus digital signal processing • can apply fourier transformation and illustrate the advantages of fast fourier transformation in the context of digital signal processing • can dimension digital filters and evaluate their performance
7	Prerequisites	None
8	Integration in curriculum	semester: 6
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Electronic examination (60 minutes) Klausur (E-Exam 60 Min.)
11	Grading procedure	Electronic examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 96030	Medizinelektronik Medical electronics	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Georg Fischer
5	Contents	The Lecture and exercise deals with the following topics: • Electronics for medical diagnostics and therapy • Challenges for medical engineering from demographic development and epidemiology of common diseases • Concepts for chronic disease management and elderly care • Regulatory framework of circuit design for medical devices • Circuit design of standard medical equipment ECG, EEG, EMG, SpO2 • Sensor principles and circuit design for biosignal acquisition • Analog-digital balance • Energy management for medical devices • Body near energy harvesting • Health data transmission • Electronic systems for ambient assisted living (AAL) • Circuit technology for lab-on-chip and microelectromechanical systems (MEMS) • Circuit technology for implants and wearable systems
6	Learning objectives and skills	Students will gain • Substantial knowledge on principles of circuit design for medical electronic devices • Substantial knowledge on circuit design for standard medical devices, e.g. ECG, EEG, EMG • Substantial knowledge on design of medical sensors • Substantial knowledge on system design for health assistance systems, wearable medical devices and implants • Ability to analyze circuit diagrams of medical electronic devices • Ability to separate medical electronic devices into their subfunctions • Ability to analyze energy budget of medical devices, particularly wearable systems • Basic ability to design electronic circuits to comply with regulatory requirements
7	Prerequisites	Completion of the modules "Circuit design" ("Schaltungstechnik") or "Electronics and circuit design" ("Elektronik und Schaltungstechnik") is recommended before attending the course.
8	Integration in curriculum	semester: 6
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Electronic examination

11	Grading procedure	Electronic examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 96220	HF-Schaltungen und Systeme	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Martin Vossiek
5	Contents	Nach einer einleitenden Übersicht über aktive Bauelemente und Schaltungen der Hochfrequenztechnik werden die Grundlagen nichtlinearer Schaltungen behandelt. Auf dieser Basis werden resistive und parametrische Mischer sowie Detektoren und Frequenzvervielfacher mit Schottky- und Varaktor-Dioden vorgestellt und beispielhafte Schaltungen besprochen. Im nächsten Abschnitt werden Mikrowellenverstärker mit Bipolar- und Feldeffekt-Transistoren für kleine und mittlere Leistungen sowie Klystron- und Wanderfeldröhrenverstärker für hohe Leistungen mit ihrem konstruktiven Umfeld vorgestellt und Schaltungsausführungen analysiert. Ausgehend von den allgemeinen Schwingbedingungen werden dann Zweipol- und Vierpol-Oszillatoren in ihrer Funktionsweise dargestellt und Berechnungsverfahren angegeben. Neben Tunneldioden- und Transistor-Oszillatoren werden auch Laufzeit-Halbleiter-Systeme in Form von Gunn-Elementen und IMPATT-Dioden sowie Laufzeit-Röhren behandelt. Verfahren zur passiven und aktiven Frequenzstabilisierung, komplexere Zusammenschaltungen von aktiven und nichtlinearen Komponenten und eine Darstellung der Einsatzbereiche von aktiven/ nichtlinearen Elemente in HF-Systemen runden die Lehrveranstaltung ab.
6	Learning objectives and skills	Die Studierenden • erwerben spezialisiertes und vertieftes Wissen über den Umgang mit aktiven und nichtlinearen Bauelementen der Hochfrequenztechnik • können physikalische Prinzipien und deren technische Umsetzung zur Realisierung von Hochfrequenz-Mischern, Detektoren, Vervielfachern, Verstärkern und Oszillatoren anwenden. • sind in der Lage, die Schaltungen der genannten HF-Komponenten eigenständig zu analysieren, zu konzipieren und zu entwickeln. • können hochfrequenten Eigenschaften von aktiven und nichtlinearen Schaltungen berechnen, darstellen und bewerten.
7	Prerequisites	• Halbleiterbauelemente • Passive Bauelemente • Elektromagnetische Felder I • Hochfrequenztechnik
8	Integration in curriculum	semester: 6

9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	B. Razavi, "RF Microelectronics", 2. Auflage Prentice Hall 2011 Zinke, O., Brunswig, H., "Hochfrequenztechnik", Band 2, Springer, Berlin, 5. Auflage, 1999. Voges, E., "Hochfrequenztechnik", 3. Auflage, Hüthig, 2004. Bächtold, W., "Mikrowellentechnik", Vieweg, Braunschweig, 1999. Bächtold, W., "Mikrowellenelektronik", Vieweg, Braunschweig, 2002. Maas, S. A., "Nonlinear Microwave and RF Circuits", Artech House, 2. Auflage, 2003. Pozar, D. M., "Microwave Engineering", 4. Auflage Wiley 2011.

1	Module name 96511	Betriebsmittel und Komponenten elektrischer Energiesysteme Operating materials and components for electrical energy supply systems	5 ECTS
2	Courses / lectures	Vorlesung: Betriebsmittel und Komponenten elektrischer Energiesysteme (2 SWS) Übung: Übungen zu Betriebsmittel und Komponenten elektrischer Energiesysteme (2 SWS) Exkursion: Kurzexkursion zu Betriebsmittel und Komponenten elektrischer Energiesysteme (0 SWS)	5 ECTS - -
3	Lecturers	Prof. Dr.-Ing. Matthias Luther Simon Linnert	

4	Module coordinator	Prof. Dr.-Ing. Matthias Luther
5	Contents	"Betriebsmittel und Komponenten elektrischer Energiesysteme" beschäftigt sich mit den Betriebsmitteln und Komponenten elektrischer Energiesysteme. Als Einleitung bekommen die Studierenden einen Überblick über die Struktur und den Aufbau der elektrischen Energieversorgung. Anschließend werden die notwendigen Berechnungsgrundlagen für die Modellierung der Komponenten erläutert. Im Hauptteil werden die einzelnen Betriebsmittel der elektrischen Energieversorgung vorgestellt und auf die mathematische Modellierung ihres Verhaltens eingegangen. Des Weiteren wird auf die Kriterien zur Dimensionierung von kompletten Anlagen, Komponenten und einzelnen Betriebsmitteln eingegangen. Abschließend werden die aktuellen Entwicklungen in der Leistungselektronik und Speichertechnik vorgestellt und erläutert. Gliederung: 1. Einführung: Grundlagen elektrischer Energiesysteme 2. Berechnungsgrundlagen 3. Ersatzschaltungen und Kenndaten von Betriebsmitteln • Freileitungen • Kabel • Transformatoren • Generatoren • Lasten • Kompensationseinrichtungen 4. Aufbau und Komponenten von Schaltanlagen 5. Bemessung und Auslegung von Anlagen und Betriebsmitteln 6. Leistungselektronische Komponenten 7. Speicher
6	Learning objectives and skills	Die Studierenden • kennen die charakteristischen Betriebsmittel und Komponenten elektrischer Energiesysteme der Primär- und Sekundärtechnik (Freileitungen, Kabel, Transformatoren, Generatoren, Lasten, Kompensationsanlagen, Leistungselektronik, Speicher, Schutzgeräte und weitere),

		• kennen die Grundsätze bei Planung und Betrieb von elektrischen Anlagen, • verstehen den konstruktiven Aufbau und die grundlegenden Funktionen einzelner Betriebsmittel und Komponenten, • verstehen das Zusammenwirken von Betriebsmitteln und Komponenten in elektrischen Energiesystemen, • wenden die erworbenen Fähigkeiten zur elektrischen Nachbildung von Betriebsmitteln und Komponenten an, • wenden die erworbenen Berechnungsgrundlagen in realitätsnahen Aufgabenstellungen an, • wenden Bemessungsgrundlagen in Anwendungsfällen für Anlagen und Betriebsmittel an und • können die Problemstellungen bei der Planung und dem Betrieb von elektrischen Anlagen verstehen und die Methoden der Lösung anwenden.
7	Prerequisites	• Grundlagen der elektrischen Energieversorgung
8	Integration in curriculum	semester: 5
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	• Herold: Elektrische Energieversorgung II. Parameter elektrischer Stromkreise - Freileitungen und Kabel Transformatoren, J. Schlembach Fachverlag, 2. Auflage, 2008 und 2010. • Oeding, Oswald: Elektrische Kraftwerke und Netze Springer-Verlag, 8. Auflage, 2016. • Schwab, A.: Elektroenergiesysteme, Erzeugung, Transport, Übertragung und Verteilung elektrischer Energie Springer-Verlag, 2.Auflage 2009.

1	Module name 96740	Analog-Digital- und Digital-Analog-Umsetzer	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr. Jürgen Röber	
5	Contents	• ADU, DAU Kenngrößen und Spezifikation • Überblick über unterschiedliche Umsetzerarchitekturen • SAR-Umsetzer Design • Abtast-Halte Glieder • Komparatoren • Rauscheffekte in Umsetzern • Delta-Sigma-ADU • Current Steering DAC • String DAC • R-2R DAC • Delta-Sigma DAC • Integration von ADUs in ein Gesamtsystem	
6	Learning objectives and skills	Die Studierenden kennen • Die wichtige Kenngrößen für Analog-Digital Umsetzer (ADU) und können die Genauigkeit von ADUs interpretieren. • Die verbreiteten ADU Architekturen und deren Vor- und Nachteile. • Die Komponenten eines SAR ADUs und wichtige Details für den integrierten Schaltungsentwurf von SAR ADUs • Verschiedene integrierte Schaltungstechniken im Entwurf von Delta-Sigma ADUs • Die richtige Verschaltung von ADUs in einer Applikation. Eine falsche Verschaltung führt schnell zu schlechter Genauigkeit. • Die verbreiteten DAU Architekturen, deren Vor- und Nachteile und deren Schaltungsprinzip. • Die grundlegenden Funktionen von Cadence und haben einen Einblick in den integrierten Entwurf von ADUs.	
7	Prerequisites	None	
8	Integration in curriculum	semester: 6	
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242	
10	Method of examination	Written or oral	
11	Grading procedure	Written or oral (100%)	
12	Module frequency	Only in summer semester	
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h	
14	Module duration	1 semester	

15	Teaching and examination language	german
16	Bibliography	

1	Module name 96801	Kommunikationsstrukturen Communication structures	5 ECTS
2	Courses / lectures	Übung: Übungen zu Kommunikationsstrukturen (2 SWS) Vorlesung: Kommunikationsstrukturen (2 SWS)	5 ECTS 5 ECTS
3	Lecturers	Jürgen Frickel	

4	Module coordinator	Jürgen Frickel
5	Contents	Einführung • Information und Kommunikation • Anwendungsgebiete - Kommunikation Strukturen und Eigenschaften von Kommunikationssystemen • Grundlegende Definitionen und Klassifikationen • Grundlegende Strukturen Protokolle und Schnittstellen • Grundlagen • Basis-Verfahren und Beispiele • TCP/IP-Protokol • Referenzmodell nach ISO/OSI • Sicherungsschicht/Data Link Layer (LLC und MAC) • Bitübertragungsschicht/Physical Layer • Übertragungsmedien Hardware in Kommunikationsstrukturen • HW-Architekturen und Funktionsblöcke • Digitale und Analoge Komponenten • Schaltungsdetails von Komponenten Grundlagen von Bussystemen • Klassifikation • Funktionale Eigenschaften • Arbitrierungs-Verfahren Leitungsgebundene Anwendungen für Rechnersysteme • Bus-Applikationen • Baustein-/IC-interne Busse (AMBA, FPI, ConTraBus, .) • Baugruppeninterne Busse (I2C, Chipsätze+Bridges, .) • Busse für Rechensysteme (VME, ISA, PCI, PCIe, AGP, .) • Peripherie-Busse (ATA, IEC, USB, Firewire, Fibre Channel, Thunderbolt .) Leitungsgebundene Anwendungen in Systemen • Feldkommunikation • Automobil, Luftfahrt, Space (CAN, MOST, LIN, MILBus, Spacewire .) • Industrie, Haustechnik (Profibus, EIB, .) • Weitverkehrsnetze • SDH, PDH, ATM,
6	Learning objectives and skills	1. Die Studierenden werden in die Lage versetzt die Konzepte und Verfahren vor allem drahtgebundener Kommunikationssysteme anzuwenden.

		2. Die Studierenden lernen die Funktionsweise und den Einsatzzweck diverser Kommunikationsprotokolle zu verstehen, und miteinander zu vergleichen. 3. Desweiteren analysieren und klassifizieren Sie grundlegende Strukturen von leitungsgebundenen Kommunikationssystemen anhand ihrer funktionalen Eigenschaften.
7	Prerequisites	None
8	Integration in curriculum	semester: 6
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written Klausur, 90min
11	Grading procedure	Written (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 96841	Multiphysics Systems and Components Multiphysics systems and components	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Georg Fischer
5	Contents	Das Modul bietet eine Einführung in die Simulationsmethode der Finiten Elemente. Dabei liegt der Schwerpunkt auf multiphysikalischen Systemen, d.h. Systemen, die den Gesetzmäßigkeiten von mindestens zwei gekoppelten physikalischen Domänen unterliegen. Themen der Vorlesung: • Mathematische Grundlagen zu Differentialgleichungen • Überblick über numerische Verfahren zur Lösung von Differentialgleichungen • Finite-Elemente-Methode (ein- und mehrdimensionale sowie zeitabhängige Probleme) • Simulation und Experiment
6	Learning objectives and skills	• Die Studierenden kennen grundlegende Klassen von Differentialgleichungen und können vorgegebene Differentialgleichungen diesen Klassen zuordnen. • Die Studierenden verstehen das Konzept gut konditionierter Differentialgleichungsprobleme. • Die Studierenden können unterschiedliche numerische Verfahren zur Lösung von Differentialgleichungen benennen und grundlegende Unterschiede erläutern. • Die Studierenden können das Vorgehen bei der Finite-Elemente-Methode erklären sowie einfache Differentialgleichungen in die schwache Form überführen sowie das zugehörige algebraische Gleichungssystem herleiten. • Die Studierenden können für eine vorgegebene Versuchsanordnung ein Simulationsmodell erstellen und analysieren. • Die Studierenden können unterschiedliche numerische Verfahren, die innerhalb der FEM genutzt werden, beispielsweise zur Lösung zeitabhängiger Probleme, erklären und im Simulationsprogramm einsetzen. • Die Studierenden können Ursachen für Diskrepanzen zwischen Simulationsmodell und Versuchsaufbau benennen sowie Methoden zur Identifikation dieser Ursachen angeben.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes)

11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 96842	Praktikum Entwurf Integrierter Schaltungen I Laboratory course: Design of Integrated Circuits I	2,5 ECTS
2	Courses / lectures	Praktikum: Praktikum Entwurf Integrierter Schaltungen I (2 SWS)	2,5 ECTS
3	Lecturers	Tobias Rumpel	

4	Module coordinator	Florian Deeg Peter Meisel
5	Contents	• Einführung in Cadence • Erstellung einer einfachen Schaltung (z.B. Inverter) in Schematic • Untersuchung dieser Schaltung • Erstellung bzw. Extrahierung der Netzliste
6	Learning objectives and skills	Die Studierenden arbeiten an den folgenden Fachkompetenzen Verstehen • Klassifizieren von Charakterisierungsmethoden und Herstellungsverfahren aus der Mikroelektronik • erklären typischer Werkzeuge und Verfahren für die Verifikation und den Entwurf mikroelektronischer Schaltungen Anwenden • analysieren von grundlegenden Schaltungselemente Erschaffen • Erstellen grundlegender Teilschaltungen und Simulation Lern- bzw. Methodenkompetenz • erwerben praktischer Erfahrungen mit typischen Werkzeugen und Verfahren für die Verifikation und den Entwurf mikroelektronischer Schaltungen Selbstkompetenz • können in Gruppen kooperativ arbeiten und Simulationen beurteilen und gegebenenfalls verbessern
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 96875	Ausgewählte Kapitel der Audiodatenreduktion Advanced topics in perceptual audio coding	2,5 ECTS
2	Courses / lectures	Vorlesung: Advanced Topics in Perceptual Audio Coding (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Jürgen Herre	

4	Module coordinator	Prof. Dr.-Ing. Jürgen Herre
5	Contents	Perceptual audio coding is ubiquitous in modern life (mp3 players, mobile phones, DVD players, computers, ...) Based on related classes (esp. Speech and Audio Processing"), this lecture aims at deepening the understanding of modern algorithms for perceptual source coding of audio. It includes an overview of the most relevant standardized coders, starting with MPEG-1 (incl. mp3) via MPEG-4 all the way to the most recent MPEG Audio standard. The significant algorithms are discussed and new approaches are described. The selected topics include: Efficient coding of several audio channels / parametric multi-channel coding Typical coding artifacts; subjective and objective quality assessment Scalable audio coding Bandwidth extension Semi-parametric audio coding Low-delay audio coding The lecture includes a number of demonstrations and audio examples to illustrate the discussed algorithms.
6	Learning objectives and skills	• Wissen - Die Studenten kennen die Hauptkomponenten eines gehörangepassten Audiocodecs, sowie die wichtigsten Algorithmen, Codierstrategien und Bewertungsmethoden. Weiterhin kennen sie die Terminologie und gängige Abkürzungen aus diesem Kontext. • Verstehen - Die Studenten verstehen, wie Designentscheidungen in Audiocodecs die letztendlich erreichte Audioqualität beeinflussen, verstehen die gebräuchlichsten Tools aus dem Bereich der gehörangepasste Audiocodierung und wie verschiedene Anwendungsszenarien das Coderdesign bestimmen. • Anwenden - Die Studenten können übliche mathematische Analysemethoden verwenden, um einfache Coder-Componenten zu beschreiben und gegebenenfalls zu modifizieren. • Analysieren - Die Studenten können Audiocodierungs-Standards und wahrnehmungsbasierte Messwerkzeuge dazu analysieren um die zugrundeliegenden Konzepte und Anforderungen zu erfassen. • Evaluieren (Beurteilen) - Die Studenten können Audiocodierungs-Standards und wahrnehmungsbasierte Messwerkzeuge evaluieren um zu beurteilen, welcher

		Standard bzw. welches Messwerkzeug das passendste ist für einen bestimmten Anwendungsfall. • Synthese - Die Studenten können eine Liste von Anforderungen und Bewertungskriterien für Audiocodecs zusammenstellen für gewünschte Anwendungsfälle. • Lern- bzw. Methodenkompetenz - Die Studenten hinterfragen bestehende Ansätze hinsichtlich ihrer Anwendbarkeit in der Praxis.
7	Prerequisites	None
8	Integration in curriculum	semester: 6
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written or oral Prüfung: Mündlich, 30min.
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 96885	Auditory Models Auditory models	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Bernd Edler
5	Contents	• Main components of the human auditory system • Common models • Mechanical models • Physiological models • Psychoacoustic models • Applications (hearing aids, audio coding, . . .)
6	Learning objectives and skills	Goals • Students understand the structure and function of the human auditory system • Students gain deeper insight into psychoacoustic phenomena, such as masking, directional and spatial hearing • Students implement and evaluate perceptual models for various applications • Students collaborate with scientists in the fields of audiology and neuroscience
7	Prerequisites	None
8	Integration in curriculum	semester: 6
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written or oral Prüfung: Mündlich, 30min.
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 96890	Music Processing - Analysis Music processing - Analysis	2,5 ECTS
2	Courses / lectures	Vorlesung: Music Processing Analysis (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Meinard Müller	

4	Module coordinator	Prof. Dr. Meinard Müller
5	Contents	Music signals possess specific acoustic and structural characteristics that are not shared by spoken language or audio signals from other domains. In fact, many music analysis tasks only become feasible by exploiting suitable music-specific assumptions. In this course, we study feature design principles that have been applied to music signals to account for the music-specific aspects. In particular, we discuss various musically expressive feature representations that refer to musical dimensions such as harmony, rhythm, timbre, or melody. Furthermore, we highlight the practical and musical relevance of these feature representations in the context of current music analysis and retrieval tasks. Here, our general goal is to show how the development of music-specific signal processing techniques is of fundamental importance for tackling otherwise infeasible music analysis problems.
6	Learning objectives and skills	Expertise Understand - The students present central tasks in music processing in their own words and outline possible solutions. - The students understand the properties of different forms of representation of music. Apply - The students apply basic algorithms for the analysis and comparison of music signals. - Students can predict how different musical properties will affect the signal analysis. Analyze - The students observe and discuss the meaning and impact of parameters in music analysis. - The students compare different methods of analyzing periodicities. Evaluate - The students question assumptions that are often implicitly made when using analytical methods. - Students estimate when methods might work when analyzing specific music signals and when they typically fail. Learning and methodological skills - The students prepare for the lecture using selected literature and Jupyter notebooks. - The students question existing approaches regarding their applicability in practice. - The students pay attention to efficiency issues in the algorithms discussed. Self-competence

- The students question their understanding of what they have learned using exercises.
- The students formulate questions and ask them to the lecturer and the audience in the lecture.

Social skills

- The students independently organize learning groups in which the subject is discussed and deepened.
- The students simulate oral exams with their fellow students.

Fachkompetenz

Verstehen

- Die Studierenden stellen zentrale Aufgabenstellungen der Musikverarbeitung in eigenen Worten dar und skizzieren Lösungsansätze.
- Die Studierenden verstehen die Eigenschaften von unterschiedlichen Darstellungsformen von Musik.

Anwenden

- Die Studierenden wenden grundlegende Algorithmen zur Analyse und zum Vergleich von Musiksignalen an.
- Die Studierenden können voraussagen, wie sich unterschiedliche musikalische Eigenschaften bei der Signalanalyse auswirken.

Analysieren

- Die Studierenden beobachten und diskutieren die Bedeutung und Auswirkung von Parametern bei der Musikanalyse.
- Die Studierenden stellen unterschiedliche Verfahren bei der Analyse von Periodizitäten gegenüber.

Evaluierten (Beurteilen)

- Die Studierenden hinterfragen Annahmen, die implizit bei der Verwendung von Analysemethoden gemacht werden.
- Die Studierenden schätzen ein, wann Methoden bei der Analyse von gewissen Musiksignalen funktionieren könnten und wann sie typischerweise versagen.

Lern- bzw. Methodenkompetenz

- Die Studierenden bereiten sich auf die Vorlesung anhand ausgewählter Literatur vor.
- Die Studierenden hinterfragen bestehende Ansätze hinsichtlich ihrer Anwendbarkeit in der Praxis.
- Die Studierenden beachten Fragen der Effizienz bei den diskutierten Algorithmen.

Selbstkompetenz

- Die Studierenden hinterfragen ihr Verständnis von dem Gelernten anhand von Übungsaufgaben.
- Die Studierenden formulieren Fragen und stellen diese in der Vorlesung an den Dozenten und die Zuhörerschaft.

Sozialkompetenz

- Die Studierenden organisieren selbständig Lerngruppen, in denen der Stoff diskutiert und vertieft wird.
- Die Studierenden simulieren mit ihren Kommilitonen mündliche Prüfungen.

7	Prerequisites	In this course, we discuss a number of current research problems in music processing or music information retrieval (MIR) covering aspects from information science and digital signal processing. We provide the necessary background information and give numerous motivating examples so that no specialized knowledge is required. However, the students should have a solid mathematical background. The lecture is accompanied by readings from textbooks or the research literature. Furthermore, the students are required to experiment with the presented algorithms using Python.
8	Integration in curriculum	semester: 6
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written or oral Prüfung: mündl. 30min
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	http://www.music-processing.de http://www.springer.com/gp/book/9783319219448

1	Module name 96940	Praktische Einführung in Machine Learning Practical introduction to machine learning	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Nico Hanenkamp
5	Contents	Folgende Themengebiete werden unter anderem behandelt: - Grundlagen Machine Learning - Grundlagen der Digitalen Signalverarbeitung - Vorgehensweise bei Machine Learning Projekten - Praktische Einführung in die Programmiersprache Python mit Jupyter Notebook/Google Colab - Praktische Übung zur Anwendung traditioneller Machine Learning Methoden - Kurze Einführung in Neuronale Netze
6	Learning objectives and skills	Die Studierenden lernen die ersten Grundlagen und Begrifflichkeiten zum Thema Machine Learning kennen und im Kontext Künstliche Intelligenz einzuordnen. Der Ablauf und die Durchführung von Machine Learning Projekten werden an praktischen Beispielen aufgezeigt und deren Potenziale und Herausforderungen diskutiert. Für die eigene Umsetzung im Rahmen der Seminararbeiten erfolgt die Einführung in die Programmiersprache Python mit der Erläuterung relevanter Bibliotheken. Die Kenntnisse werden durch die eigenständige Bearbeitung einer Aufgabenstellung aus den Bereichen Audioanalyse zur Überwachung von Maschinen und Prozessen vertieft.
7	Prerequisites	Empfohlen: Grundkenntnisse Python Programmierung
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable • Hausarbeit, 10-15 DIN A4 Seiten • Python Code
11	Grading procedure	Variable (100%) • Hausarbeit: 50% • Python Code: 50%
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 22 h Independent study: 53 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 97110	Technische Produktgestaltung Technical product design	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Sandro Wartack
5	Contents	• Einführung in die Technische Produktgestaltung • Baustrukturen technischer Produkte • Fertigungsgerechte Werkstückgestaltung • toleranzgerechtes Konstruieren • kostengerechtes Konstruieren • beanspruchungsgerechtes Konstruieren • werkstoffgerechtes Konstruieren • Leichtbau • umweltgerechtes Konstruieren • nutzerzentrierte Produktgestaltung
6	Learning objectives and skills	Fachkompetenz Wissen Im Rahmen von TPG erwerben die Studierenden Kenntnisse zur Berücksichtigung verschiedener Aspekte des Design-for-X bei der Entwicklung technischer Produkte. Nach der erfolgreichen Teilnahme kennen sie die jeweiligen Gestaltungsrichtlinien und zugehörige Methoden. Dies sind im Einzelnen: • Wissen über Möglichkeiten zur Umsetzung des Leichtbaus und daraus abgeleitet über spezifische Gestaltungsrichtlinien, die im Rahmen des Leichtbaus zu berücksichtigen sind, hierzu: Beanspruchungsgerechtes Konstruieren (Kraftfluss, Prinzip der konstanten Gestaltfestigkeit, Kerbwirkung, Prinzip der abgestimmten Verformung, Prinzip des Kräfteausgleichs) • Wissen über werkstoffgerechtes Konstruieren (Anforderungs- und Eigenschaftsprofil, wirtschaftliche Werkstoffauswahl, Auswirkung der Werkstoffwahl auf Fertigung, Lebensdauer und Gewicht) • Wissen über die Auswirkungen eines Produktes (und insbesondere der vorhergehenden Konstruktion) auf Umwelt, Kosten und den Nutzer, hierzu: Umweltgerechtes Konstruieren (Recycling, Einflussmöglichkeiten in der Produktentwicklung, Strategien zur Berücksichtigung von Umweltaspekten, Life Cycle Assessment, Produktinstandsetzung, Design for Recycling) • Wissen über kostengerechtes Konstruieren (Beeinflussung der Lebenslauf-, Herstell- und Selbstkosten in der Produktentwicklung, Auswirkungen der Stückzahl und der Fertigungsverfahren, Entwicklungsbegleitende Kalkulation) • Wissen über nutzerzentrierte Produktentwicklung (Anthropometrie, Nutzerintegration in der Produktentwicklung,

Mensch-Maschine-Schnittstellen, Beeinträchtigungen im Alter, Universal Design, Gestaltungsrichtlinien nach dem SENSI-Regelkatalog, etc.)

- Wissen über spezifische Gestaltungsrichtlinien der Fertigungsverfahren des Urformens" (Gießen, Pulvermetallurgie, Additive Fertigung)
- Wissen über spezifische Gestaltungsrichtlinien der Fertigungsverfahren des Umformens" (Schmieden, Walzen, Biegen, Scheiden, Tiefziehen, Stanzen, Fließpressen)
- Wissen über spezifische Gestaltungsrichtlinien der Fertigungsverfahren des Trennens" (Zerteilen, Drehen, Fräsen, Bohren, Schleifen, Erodieren)
- Wissen über spezifische Gestaltungsrichtlinien der Fertigungsverfahren des Fügens" (Schweißen, Löten, Nieten, Durchsetzfügen, Kleben, Fügen durch Urformen)
- Wissen über spezifische Gestaltungsrichtlinien der Fertigungsverfahren des Beschichtens und Stoffeigenschaften ändern" (Schmelztauchen, Lackieren, Thermisches Spritzen, Physical Vapour Deposition, Chemical Vapour Deposition, Galvanische Verfahren, Pulverbeschichten, Vergüten, Glühen)
- Wissen über spezifische Gestaltungsrichtlinien des montagegerechten Konstruierens bzgl. der Baustruktur technischer Produkte (Integral-, Differential und Verbundbauweise, Produktstrukturierung, Variantenmanagement, Modularisierung) und des Montageprozesses (Gestaltung der Fügeteile und Fügestellen, Automatisches Handhaben und Speichern, Toleranzausgleich, DFMA)
- Wissen über spezifische Inhalte des toleranzgerechten Konstruierens (insbesondere Grundlage der geometrischen Tolerierung und die Vorgehensweise zur Vergabe von Toleranzen)

Verstehen

Nach erfolgreichem Abschluss des Moduls "Technische Produktgestaltung" verfügen die Studierenden über Verständnisse hinsichtlich der technischen und nicht-technischen Einflussfaktoren und deren Abhängigkeiten bei der Gestaltung technischer Produkte ausgehend von der Produktstruktur bis zur konstruktiven Bauteilgestaltung. Hierbei stehen besonders die folgenden Verständnisse im Fokus:

- Verständnis über die Spezifikation von Toleranzen, Passungen und Oberflächen in Technischen Zeichnungen unter Berücksichtigung deren Auswirkungen auf Fertigung, Montage und den Betrieb des Produktes, hierzu:
Verständnis der Vorgehensweise zur Toleranzspezifikation sowie erforderlicher Grundlagen zur Tolerierung von Bauteilen (Allgemeintoleranzen, wirkliche und abgeleitete Geometrieelemente, Hüllbedingung, Unabhängigkeitsprinzip,

Inklusion verschiedener Toleranzarten, Bezugssysteme und Ausrichtungskonzepte, statistische Toleranzanalyse, etc.)

- Verständnis über Fertigung und Montage sowie über die Bedeutung des Design-for-X und insbesondere des fertigungsgerechten Konstruierens im Produktentwicklungsprozess
- Verständnis über die Berücksichtigung nicht-technischer Faktoren, wie beispielsweise Umwelt-, Kosten- und Nutzeraspekten, und deren Wechselwirkungen bei der Gestaltung technischer Produkte.

Anwenden

Die Studierenden wenden im Rahmen von Übungsaufgaben Gelerntes an. Dabei werden bestehende Entwürfe und Konstruktionen durch die Studierenden entsprechend der vermittelten Gestaltungsrichtlinien optimiert und neue Konstruktionen unter Einhaltung dieser Gestaltungsrichtlinien erschaffen. Dies beinhaltet im Einzelnen:

- Erstellung der fertigungsgerechten und montagegerechten Tolerierung von Bauteilen. Dies umschließt folgende Tätigkeiten: Bestimmen der zugrundeliegenden Bezugssysteme und Ausrichtungskonzepte; Bestimmen des Tolerierungsgrundsatzes. Integration von, durch Normen definierte Toleranz- und Passungsvorgaben in bestehende Tolerierungen; Zusammenfassen kombinierbarer Form- und Lagetoleranzen zu Zeichnungsvereinfachung; Festlegung der Größen der Toleranzzonen aller vergebenen Toleranzen.
- Optimierung der Tolerierung anhand der statistischen Toleranzanalyse. Dies umschließt folgende Tätigkeiten: Erkennen und Ableiten der analytischen Schließmaßgleichungen; Definition der zugrundeliegenden Toleranzwerten und zugehörigen Wahrscheinlichkeitsverteilungen; Berechnung der resultierenden Wahrscheinlichkeitsverteilungen der Schließmaße; analytische Bestimmung der statistischen Beitragsleistung mittels lokaler Sensitivitätsanalysen; Beurteilung der Ergebnisse und ggf. anschließende Anpassung der Tolerierung der Bauteile; Transfer der Ergebnisse auf zeitabhängige Mechanismen (kinematische Systeme).
- Änderung der Gestaltung von Bauteilen, bedingt durch die Änderung der zu fertigenden Stückzahl der Baugruppe. Dies umschließt die folgenden Tätigkeiten: Bestimmung des konstruktiven Handlungsbedarfs; Anpassung der Gestaltung der Bauteile insbesondere hinsichtlich der fertigungsgerechten und der montagegerechten Gestaltung. Gestaltung der erforderlichen Werkzeuge zur Fertigung der Bauteile und Bewertung dieser bzgl. der resultierenden Kosten.

Analysieren

- Aufzeigen von Querverweisen zu den im Modul Produktionstechnik zu erwerbenden Kompetenzen über die Hauptgruppen der Fertigungsverfahren nach DIN 8580
- Aufzeigen von Querverweisen zu den im Modul Handhabungs- und Montagetechnik zu erwerbenden Kompetenzen über montagegerechtes Konstruieren
- Aufzeigen von Querverweisen zu den im Modul Umformtechnik zu erwerbenden Kompetenzen über Fertigungsverfahren der Hauptgruppe Umformen nach DIN 8580

Evaluieren (Beurteilen)

Anhand der erlernten Grundlagen über unterschiedliche Aspekte des Design-for-X, deren Berücksichtigung bei der Gestaltung technischer Produkte durch Gestaltungsrichtlinien, Methoden, und Vorgehensweisen sowie den dargelegten Möglichkeiten zur Rechnerunterstützung können die Studierenden kontextbezogene Richtlinien für die Gestaltung technischer Produkte in unbekannten Konstruktionsaufgaben auswählen und deren Anwendbarkeit einschätzen. Zudem sind sie in der Lage konträre Gestaltungsrichtlinien aufgabenspezifisch abzuwägen.

Erschaffen

Die Studierenden werden durch die erlernten Grundlagen befähigt, konkrete Verbesserungsvorschläge zu bestehenden Konstruktionen hinsichtlich unterschiedlicher Design-for-X Aspekte eigenständig zu erarbeiten. Zudem sind sie in der Lage technische Produkte so zu gestalten, dass diese verschiedenste technische und nicht-technische Anforderungen (fertigungsbezogene Anforderungen, Kostenanforderungen, Umweltanforderungen, Nutzeranforderungen, etc.) bedienen. Darüber hinaus werden die Studierenden in die Lage versetzt, Gestaltungsrichtlinien für neuartige Fertigungsverfahren aus grundlegenden Verfahrenseigenschaften abzuleiten und bei der Gestaltung technischer Produkte anzuwenden.

Lern- bzw. Methodenkompetenz

Befähigung zur selbständigen Gestaltung von Produkten und Prozessen gemäß erlernter Vorgehensweisen und Richtlinien sowie unter verschiedensten Design-for-X-Aspekten sowie zur objektiven Bewertung bestehender Produkte und Prozesse hinsichtlich gestellter Anforderungen des Design-for-X.

Selbstkompetenz

Befähigung zur selbständigen Arbeitseinteilung und Einhaltung von Meilensteinen. Objektive Beurteilung sowie Reflexion der eigenen Stärken und Schwächen sowohl in fachlicher (u. a. Umsetzung der gelehrten Richtlinien des Design-for-X in der Konstruktion) als auch in sozialer Hinsicht (u. a. Erarbeitung von Lösungen und Kompromissen im interdisziplinären Team).

Sozialkompetenz

Die Studierenden organisieren selbstständig die Bearbeitung von Übungsaufgaben in kleinen Gruppen und erarbeiten gemeinsam Lösungsvorschläge für die gestellten Übungsaufgaben. In der

		gemeinsamen Diskussion erarbeiteter Lösungen geben Betreuer und Kommilitonen wertschätzendes Feedback.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (120 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 97246	Qualitätsmanagement Quality management	5 ECTS
2	Courses / lectures	Vorlesung: Qualitätstechniken - QTeK - vhb (2 SWS) Vorlesung: Qualitätsmanagement QMaK (2 SWS)	- -
3	Lecturers	Prof. Dr.-Ing. Tino Hausotte	

4	Module coordinator	Prof. Dr.-Ing. Tino Hausotte
5	Contents	*Qualitätsmanagement I - Qualitätstechniken für die Produktentstehung [QM I]* • Einführung und Begriffe • Grundwerkzeuge des Qualitätsmanagements • Erweiterte Werkzeuge des Qualitätsmanagements • Qualitätsmanagement in der Produktplanung (QFD) • Qualitätsmanagement in der Entwicklung und Konstruktion (DR, FTA, ETA, FMEA) • Versuchsmethodik • Maschinen- und Prozessfähigkeit, Qualitätsregelkarten • Zuverlässigkeitstechniken • Qualitätsmanagementsystem - Aufbau und Einführung • [Grundwerkzeuge des QM (Einsendaufgabe)] • [QFD und FMEA (Einsendaufgabe)] • [Versuchsmethodik (Einsendaufgabe)] • [SPC (Einsendaufgabe)] *Qualitätsmanagement II - Phasenübergreifendes Qualitätsmanagement [QM II]* • Qualitätsmanagementsystem - Auditierung und Zertifizierung • Total Quality Management und EFQM-Modell • Ausbildung und Motivation • Kontinuierliche Verbesserungsprogramme und Benchmarking • Problemlösungstechniken und Qualitätszirkel • Qualitätsbewertung • Qualität und Wirtschaftlichkeit • Six Sigma • Qualitätsmanagement bei Medizinprodukten • [Qualitätsbewertung (Übung)] • [Qualitätsbezogene und Wirtschaftlichkeit (Übung)]
6	Learning objectives and skills	Nach dem Besuch des Moduls sind die Teilnehmenden in der Lage, Wissen: • ◦ die Werkzeuge, Techniken und Methoden des Qualitätsmanagements entlang des Produktlebenszyklus darzustellen ◦ die Zuverlässigkeit von Systemen zu beschreiben ◦ Wissen zu Qualitätsmanagement als unternehmens- und produktlebenszyklusübergreifende Strategie zu veranschaulichen

		◦ Anforderungen, Aufbau, Einführung sowie die Auditierung und Zertifizierung von Qualitätsmanagementsystemen darzustellen ◦ die grundlegenden Qualitätsmethoden, -techniken und -werkzeuge auf ein anderes Problem zu übertragen ◦ Prozesse mit Hilfe der statistischen Prozesslenkung (SPC), Qualitätsregelkarten und Prozessfähigkeitsindizes zu beschreiben ◦ Business Excellence anhand Total Quality Management (TQM), Unternehmensbewertungsmodelle wie EFQM und kontinuierlicher Verbesserungsprozesse im Unternehmen auszuführen ◦ die Wirtschaftlichkeit von Qualitätsverbesserungsmaßnahmen zu demonstrieren ◦ die Methodik Six Sigma" zu beschreiben und dem Kontext der Qualitätsverbesserung zuzuordnen ◦ mit Hilfe der Qualitätsmethoden, -techniken und -werkzeugen Probleme zu analysieren ◦ statistische Versuchspläne auf praktische Probleme zu übertragen und aus den Ergebnissen die Zusammenhänge und Einflüsse der Faktoren zu interpretieren ◦ Handlungsgrundlagen hinsichtlich Ausbildungs-, Motivations- und Organisationsverbesserung zu ermitteln ◦ statistische Auswertungen zu interpretieren und neue Probleme auf statistische Auffälligkeiten zu testen ◦ die Qualität mit etablierten Vorgehensweisen zu bewerten
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (120 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	• Kamiske, G. F.; Brauer, J.-P.: Qualitätsmanagement von A - Z, Carl Hanser Verlag, München 2011 • Pfeifer, T.; Schmitt, R.: Masing Handbuch Qualitätsmanagement, Hanser, München 2021

1	Module name 97500	Laborpraktikum Digitaler ASIC-Entwurf Laboratory: Digital ASIC design	2,5 ECTS
2	Courses / lectures	Praktikum: Praktikum Digitaler ASIC-Entwurf (Blockpraktikum) (3 SWS)	2,5 ECTS
3	Lecturers	Jürgen Frickel	

4	Module coordinator	Jürgen Frickel
5	Contents	In diesem Praktikum wird jeweils in Zweiergruppen eine komplexe digitale Schaltung für ein FPGA entworfen, Entwurfsziel sind hardware- und grafikorientierte Anwendungen, die ohne Prozessor/Software als reine Hardware-Lösung entwickelt und realisiert werden müssen. Hierzu müssen die Teilnehmer zu Beginn eine rudimentär vorgegebene Systemspezifikation analysieren, verbessern und verfeinern, eine Systemidee entwickeln, das geplante System partitionieren und auf Module aufteilen. Die angestrebten Lösungen werden in regelmässigen Kurzvorträgen mit der Gesamtgruppe diskutiert. Die in der Hardware-Beschreibungssprache VHDL entworfenen Module können dann mit Hilfe des Entwurfswerkzeugs (aktuell: XILINX Vivado) spezifiziert, simuliert, verifiziert und abschließend für die Ziel-Hardware synthetisiert werden. Hierbei ist außer der Schnittstellenproblematik zwischen den Modulen auch der Aspekt des simulations- und testfreundlichen Entwurfs zu beachten. Mit einer vorhandenen FPGA-Testumgebung (Evaluation/Education Board) wird der Funktions- und Systemtest auf realer Hardware durchgeführt. Nach der Verifikation und Zusammenschaltung aller Module erfolgt ein abschließender Funktionstest und Bewertung (Größe, Geschwindigkeit, Funktionsumfang, Effizienz, etc.) der Schaltung in Form einer Demonstration vor der Gesamtgruppe.
6	Learning objectives and skills	Fachkompetenz Anwenden Die Studierenden setzen die vorab (in einer anderen LV) erlernte Hardware-Beschreibungssprache VHDL in ihrem vollen Umfang zur Spezifikation und Implementierung eines komplexen, digitalen Systems ein. Analysieren Die Studierenden analysieren ein nur rudimentär beschriebenes digitales mikroelektronisches System, untersuchen mögliche Lösungsansätze und strukturieren diese Lösungsansätze in handhabbare Module. Evaluieren (Beurteilen) Die Studierenden diskutieren und bewerten im Rahmen von Kurzvorträgen eigene und fremde Lösungsvorschläge zum Systementwurf, vergleichen diese nach eigenen Kriterien, und wählen dann hiermit die besten Lösungen zur Realisierung aus.

		Die Studierenden bewerten nach Fertigstellung des Systementwurfs nach verschiedenen Kriterien (Größe, Geschwindigkeit=längster Pfad, Performance, Ästhetik, Code-Qualität) ihre und die anderen Entwürfe. Erschaffen Wegen der sehr knappen Auslegung der gegebenen Spezifikation der Systembeschreibung konzipieren die Studierenden ganz eigene, individuelle Lösungen für die Funktionsmodule und das Gesamtsystem. Lern- bzw. Methodenkompetenz Die Studierenden erlernen die Methodik zur Transformation einer Systemidee in eine digitale Realisierung. Sozialkompetenz Studierende erlernen, Problemstellungen in Gruppenarbeit gemeinsam zu lösen. Die Studierenden erarbeiten ihre Lösungen in Zweiergruppen und erläutern bzw. verteidigen diese in Kurzvorträgen gegenüber der Gesamtgruppe.
7	Prerequisites	dringend empfohlen: • Digitaltechnik (oder ähnliche Grundlagen-LV, z.B. TI-1) • V+Ü "Hardware-Beschreibungssprache VHDL" (oder andere gleichwertige LVen) • oder: nachgewiesene gute Kenntnisse/praktische Erfahrungen in VHDL, z.B. durch Praktikanten- oder Werkstudententätigkeit, intensives Eigenstudium, etc.
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement unbenotet, während des Praktikums je Zweier-Gruppe: • 4 Zwischenpräsentationen (je 5 Min.) • 1 Abschlusspräsentation mit Demonstration (10 Min.) Nachbereitung je Zweier-Gruppe: • 1 schriftliche Versuchs-Dokumentation (3-5 Seiten)
11	Grading procedure	Practical achievement (pass/fail) Praktikumsleistung: Erfüllung der Aufgabenstellung (60%), Präsentation der Ergebnisse (20%), Dokumentation der Ergebnisse (20%)
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 45 h Independent study: 30 h
14	Module duration	1 semester
15	Teaching and examination language	german english
16	Bibliography	Frickel J.; Skript der LV "Hardware-Beschreibungssprache VHDL" Xilinx; Handbuch Xilinx Vivado Lehmann G.; Wunder B.; Selz M.: Schaltungsdesign mit VHDL.

	Poing Franzis 1994 Bleck Andreas: Praktikum des modernen VLSI-Entwurfs. Stuttgart Teubner 1996

1	Module name 97720	Laborpraktikum Systematischer Entwurf programmierbarer Logikbausteine Laboratory course: Systematic design with programmable logic devices (PLD)	2,5 ECTS
2	Courses / lectures	Praktikum: Praktikum für systematischen Entwurf programmierbarer Logikbausteine (3 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Robert Weigel Albert-Marcel Schrotz	

4	Module coordinator	Prof. Dr.-Ing. Robert Weigel
5	Contents	In diesem Praktikum wird eine Einführung in den systematischen Entwurf Programmierbarer Logikbausteine geben. Außerdem werden Grundkenntnisse in der Hardwarebeschreibungs- und Programmiersprache VHDL vermittelt. Auch alternative Eingabeformate, wie die Fuse-Map oder über Einfügen von Schaltplänen werden vorgestellt. Nach der Simulation werden die erstellten Programme auf realer Hardware, einem FPGA-Board, per In-System-Programmierung" getestet. Es besteht Anwesenheitspflicht.
6	Learning objectives and skills	• Die Studierenden erlangen grundlegende Kenntnisse in VHDL • Die Studierenden verstehen die der Hardware-Programmierung zu Grunde liegenden Systematik • Die Studierenden analysieren und vergleichen unterschiedliche Ansätze von Hardware-Beschreibungsmöglichkeiten • Die Studierenden vertiefen die Grundlagen der Digitaltechnik • Die Studierenden erlangen die Fähigkeit, einfache Problemstellungen systematisch in eine Hardwarebeschreibung umzusetzen
7	Prerequisites	Empfohlene Vorkenntnisse: Grundlagen digitaler Schaltungen
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Practical achievement 1. Vorbereitung aller im Skript enthaltenen Versuche vor Besuch des Praktikums. Details finden sich im Kursmaterial. Die Vorbereitung wird am Anfang des jeweiligen Versuchs überprüft (ausreichend/nicht ausreichend). 2. Erfolgreiche Durchführung 5 Versuche (1 Tag/Versuch) mit anschließender Abnahme durch den Betreuer 3. Vollständige und ausführliche schriftliche Dokumentation (ungefähr 0,5 Seiten/Versuch) der Versuche und Beantwortung aller im Skript enthaltenen Fragen 4. Zum erfolgreichen Bestehen des Kurses sind 5 ausreichende Versuchsvorbereitungen, 5 ausreichende Versuchsdurchführungen sowie eine ausreichende Dokumentation gefordert.
11	Grading procedure	Practical achievement (pass/fail)

12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 45 h Independent study: 30 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	Tietze/Schenk: Halbleiter-Schaltungstechnik, Springer Verlag

1	Module name 92539	Drahtlose Automobilelektronik Wireless automotive electronics	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Norman Franchi
5	Contents	Im Rahmen dieses Modules werden die Grundlagen und technische Ausführung drahtloser Fahrassistenzsysteme vermittelt. Elektrofahrzeuge werden nicht nur die heute bereits in der Oberklasse verfügbaren Fahrassistenzsysteme nutzen sondern weitere E-Mobility spezifische Anwendung insbesondere zur Energie- und Reichweitoptimierung. Drahtlose Kommunikation zwischen Fahrzeug und Ladeeinrichtungen, zwischen Fahrzeugen untereinander, genaue Ortung und Streckenprognose sowie autonomes energiesparendes Fahren mit Radar-Abstandsreglung spielen hier eine wichtige Rolle. In diesem Modul werden diese modernen Entwicklungen adressiert und die dafür notwendigen Grundlagen erarbeitet. Grundlagen: • Funkkanaleigenschaften • Modellierung • Modulation, Codierung, Vielfachzugriff Fahrzeugkommunikationssysteme: • Übertragungssysteme für die Fahrassistenz • Car-to-Car und Car-to-X-Kommunikation • Breitbandige In-Car-Datenübertragung Fahrzeugsensorik: • Fahrzeugortung (lokal und global) • Automobilradar und Umfeldüberwachung • Sensorische Erfassung von Bioparametern im Fahrzeug
6	Learning objectives and skills	Die Studierenden sind nach der erfolgreichen Teilnahme am Modul in der Lage: • Relevante Funkkanaleigenschaften und Modelle für spezifische Anwendungs- und Betriebsszenarien zu klassifizieren • Modulationstechniken zu erläutern und zu bewerten • Moderne Codierungs- und Vielfachzugriffstechniken zu erläutern • Architekturen und Anwendungen von Fahrzeugkommunikationssystemen zu erläutern und zu analysieren

		Architekturen und Anwendungen von Fahrzeugsensoriksystemen zu erläutern und zu analysieren
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 15 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 96313	Felder und Wellen in optoelektronischen Bauelementen (V-Fel-Wel) Fields and waves in optoelectronic components (V-Fel-Wel)	5 ECTS
2	Courses / lectures	Vorlesung: Felder und Wellen in optoelektronischen Bauelementen (2 SWS) Übung: Übung zu Felder und Wellen in optoelektronischen Bauelementen (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Bernd Witzigmann Dr.-Ing. Friedhard Römer	

4	Module coordinator	Prof. Dr. Bernd Witzigmann
5	Contents	Elektromagnetische Feldtheorie für Wellenleiter und Resonatoren Kurze Einführung in die Quantenphysik/Halbleiterttheorie Theorie Licht-Materie Wechselwirkung Glasfaser Halbleiterlaser Photodiode Modulator
6	Learning objectives and skills	Die Studierenden geben die Grundbegriffe der optoelektronischen Bauelemente und der faserbasierten Informationsübertragung wieder wenden die Grundgleichungen der elektromagnetischen Feldtheorie auf optoelektronische Komponenten an klassifizieren Laser und Photodioden anhand unterschiedlicher Gesichtspunkte beschreiben, skizzieren und vergleichen den Aufbau und die Materialzusammensetzung unterschiedlicher Bauelemente können anhand der vermittelten Modelle und Beschreibungen die Funktionsweise und Spezifikationen von Lasern, Modulatoren, Photodioden und Wellenleitern beurteilen
7	Prerequisites	Sprache wird zu Vorlesungsbeginn vom Dozierenden festgelegt
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (60 minutes) Klausur, schriftlich, Dauer 60 min
11	Grading procedure	Written examination (100%) 100 % der Klausur
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german or english

16	Bibliography	Folien zur Vorlesung Shun Lien Chuang: Physics of Photonic Devices" 2012 (Wiley) Voges und Petermann: Optische Kommunikationstechnik" 2002 (Springer) Coldren and Corzine: Diode Lasers and Photonic Integrated Circuits" 1995 (Wiley) Saleh and Teich: Fundamentals of Photonics" 1991 (Wiley)

1	Module name 46930	Signalkonditionierung in integrierten Analogschaltungen Signal conditioning in analogue integrated circuits	2,5 ECTS
2	Courses / lectures	Übung: Übungen zu Signalkonditionierung in integrierten Analogschaltungen (2 SWS) Vorlesung: Signalkonditionierung in integrierten Analogschaltungen (2 SWS)	- 5 ECTS
3	Lecturers	Albert-Marcel Schrotz Dr. Jürgen Röber	

4	Module coordinator	Dr. Jürgen Röber	
5	Contents	• Entwurf präziser Analogschaltungen • Präzise Stromspiegel u.a. für niedrige Versorgungsspannungen • Entwurf von VC-Operationsverstärkern (engl.: OTAs), Eingangsstufe mit gefalteter Kaskode, Rückkopplung für Gleichaktpotential • Entwurf mehrstufiger OPVs • Tipps & Tricks fürs OPV-Design: rail-to-rail Ein- und Ausgangsstufen, dynamische Kompensation des Offset-Fehlers • Schaltungen zur Arbeitspunkteinstellung und on-chip Referenzen • Rauschen in analogen Schaltungen • Power Management analoger Schaltungen (lineare Spannungsregler, getaktete Spannungsregler) • Grundlagen von Class-D (Audio) Verstärkern	
6	Learning objectives and skills	Die Studierenden sind nach der erfolgreichen Teilnahme am Modul in der Lage: • die grundlegenden Operationsverstärkerschaltungen zu verstehen • Das Prinzip der Rückkopplung zur Verbesserung der Eigenschaften von den integrierten Schaltungen einzusetzen • Offsetkompensationsmethoden bei den integrierten Operationsverstärkern zu verstehen und zu bewerten • Rauschen in analogen integrierten Schaltungen zu analysieren und zu optimieren • die Architekturen der Strom- und Spannungsreferenzen zu verstehen und zu bewerten • Die grundlegenden Funktionen der IC- Entwicklungssoftware Cadence zu bedienen	
7	Prerequisites	None	
8	Integration in curriculum	semester: 1	
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242	
10	Method of examination	Written or oral	

11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 93105	Sichere Systeme Secure Systems	5 ECTS
2	Courses / lectures	Übung: Sichere Systeme Übung 10 (2 SWS) Übung: Sichere Systeme Übung 4 (2 SWS) Übung: Sichere Systeme Übung 12 (2 SWS) Übung: Sichere Systeme Übung 7 (2 SWS) Übung: Sichere Systeme Übung 11 (2 SWS) Übung: Sichere Systeme Übung 6 (2 SWS) Übung: Sichere Systeme Übung 1 (2 SWS) Übung: Sichere Systeme Übung 2 (2 SWS) Übung: Sichere Systeme Übung 5 (2 SWS) Übung: Sichere Systeme Übung 8 (2 SWS) Übung: Sichere Systeme Übung 9 (2 SWS) Übung: Sichere Systeme Übung 3 (2 SWS) Vorlesung: Sichere Systeme (2 SWS)	2,5 ECTS 2,5 ECTS 2,5 ECTS 2,5 ECTS 2,5 ECTS 2,5 ECTS 2,5 ECTS 2,5 ECTS 2,5 ECTS 2,5 ECTS 2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Felix Freiling Maximilian Eichhorn	

4	Module coordinator	Prof. Dr.-Ing. Felix Freiling
5	Contents	Die Vorlesung gibt einen einführenden Überblick über Konzepte und Methoden der IT-Sicherheit. Themen (unter anderem): • Angreifer und Schutzziele • Cyberkriminalität und Strafbarkeit • Ethik und Privatsphäre • grundlegende Muster von Unsicherheit in technischen Systemen • grundlegende Sicherheitsmechanismen • Techniken der Sicherheitsanalyse • ausgewählte Beispiele aus dem Bereich der Kryptographie und Internetsicherheit (Web-Security) In der Übung werden die Themen der Veranstaltung beispielhaft eingeübt. Themen (unter anderem): • Kryptanalyse und Angreifbarkeit kryptographischer Protokolle • Schutzziele und Strafbarkeit • Zertifikate und Public-Key-Infrastrukturen • Web-Security • anonyme Kommunikation • formale Sicherheitsanalyse • Sicherheitstesten
6	Learning objectives and skills	Die Teilnehmenden erwerben einen Überblick über Konzepte und Methoden aus dem Bereich der IT-Sicherheit und können diese im Kontext der Informatik und der Lebenswirklichkeit anhand von Beispielen einordnen und erläutern. Die Studierenden können die

		Schwächen in Internetprotokollen erkennen und benennen. Sie können außerdem erläutern, wie man diese Schwachstellen ausnutzt und welche technischen und organisatorischen Maßnahmen geeignet sind, diese Schwachstellen zu vermeiden. Die Studierenden lernen, die Wirksamkeit von IT-Sicherheitsmechanismen im gesellschaftlichen Kontext und in Kenntnis professioneller Strukturen der Cyberkriminalität aus technischen, ethischen und rechtlichen Perspektiven zu bewerten.
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	• Dieter Gollmann: Computer Security. 3. Auflage, Wiley, 2010. • Joachim Biskup: Security in Computing Systems. Springer, 2008. Weitere Literatur wird in der Vorlesung bekanntgegeben.

1	Module name 64620	Numerik I für Ingenieure Numerics for engineers I	5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Dr. Michael Fried apl. Prof. Dr. Wilhelm Merz
5	Contents	- Basics: direct and iterative solution methods for linear and nonlinear systems of equations, interpolation, quadrature, extrapolation - Numerical solution of ordinary differential equations, Runge-Kutta methods, stability and convergence, multi-step methods
6	Learning objectives and skills	The students learn: - different numerical methods for the solution of linear systems of equations - interpolation techniques - basic quadrature methods - methods for solving ordinary differential equations - judging the quality of those methods/techniques - algorithmic implementation of those methods
7	Prerequisites	Courses "Mathematics for Engineers I-III"
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (60 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german english
16	Bibliography	- Own scripts - H.-R. Schwarz, N. Köckler: Numerische Mathematik

1	Module name 95340	Automotive Engineering I Automotive engineering	2,5 ECTS
2	Courses / lectures	Vorlesung: Automotive Engineering 1 (2 SWS)	2,5 ECTS
3	Lecturers	Jan Fröhlich Jean-Marc Gales Annalena Hartmann Prof. Dr.-Ing. Jörg Franke	

4	Module coordinator	Prof. Dr.-Ing. Jörg Franke
5	Contents	This module is aimed at all engineering majors and students interested in working in the automotive industry or its related fields. It explores topics from product development to production and sales. The aspect of interdisciplinary collaboration is presented from various perspectives. On the one hand, insights into the technical and design implementation of key elements of an automobile are touched upon. On the other hand, strategic and business-related factors are illuminated and their significance for the engineer is deepened. The goal is to impart a comprehensive understanding of the complexities of the automotive industry. The automobile is increasingly one of the most complex industrial goods. It is shaped by societal requirements, legal restrictions, and a wide variety of market and customer demands worldwide. Learn about the challenges facing engineering in the automotive industry, understand the interrelationships, and develop solutions. The following thematic focuses are covered in the module: • Overview of the processes and framework for development in the automotive industry. • Product Development • The Production Process in the Automotive Industry • Integrated Validation • Commercial Organization: Market Launch, Marketing Concepts, Service, and Aftermarket Strategies • Electrification, Hybrid, Alternative Drives • In-Vehicle Electronics: Driver Assistance, Navigation, Communication • New Technologies for Car Body Manufacturing • Passive and Active Safety: Trends and Market Trends, Technical Solutions • Development of Driving Dynamics • IT Systems in the Automotive Industry • Top Performance as Fascinating Challenges (Design Studies, Experimental Vehicles, Racing) • Quality Management
6	Learning objectives and skills	After completing the module, students will be able to: • Provide an overview of product development through to series production • Understand the production processes in the automotive industry

		• Understand support processes such as integrated validation • Name the advantages and disadvantages of different drive technologies • Have an overview of electrical and electronic systems in vehicles • Understand influences on vehicle dynamics
7	Prerequisites	None
8	Integration in curriculum	semester: 5
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (60 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	The lecture recordings and documents can be found in the StudOn group.

1	Module name 999823	BWL für Ingenieure (BW 1 + BW 2) Business administration for engineers (BW 1 + BW 2)	2,5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Prof. Dr. Kai-Ingo Voigt
5	Contents	BW 1 (konstitutive Grundlagen): Grundlagen und Vertiefung spezifischer Aspekte der Rechtsform-, Standort-, Organisations- und Strategiewahl BW 2 (operative Leistungsprozesse): Betrachtung der unternehmerischen Kernprozesse Forschung und Entwicklung mit Fokus auf das Technologie- und Innovationsmanagement, Beschaffung und Produktion sowie Marketing und Vertrieb
6	Learning objectives and skills	Die Studierenden • erwerben Kenntnisse über Grundfragen der allgemeinen Betriebswirtschaftslehre • verstehen die Kernprozesse der Unternehmung und die damit verbundenen zentralen Fragestellungen • erwerben ein Verständnis für den Entwicklungsprozess der Unternehmung sowie deren Kernprozesse, insbesondere verfügen sie über breites und integriertes Wissen einschließlich der wissenschaftlichen Grundlagen in den Bereichen Forschung und Entwicklung, Beschaffung, Produktion, Marketing und Vertrieb. • können Fragen des Technologie- und Innovationsmanagements anhand der Anwendung ausgewählter Methoden und Instrumente erschließen • wissen um die Bestandteile eines Businessplans, deren Bedeutung und sind in der Lage, diese zu verfassen und zu beurteilen
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (60 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	Voigt, Industrielles Management, 2008

1	Module name 118154	Aufbau- und Verbindungstechnik in der Leistungselektronik Packaging technologies for power electronics	2,5 ECTS
2	Courses / lectures	Vorlesung: Aufbau- und Verbindungstechnik in der Leistungselektronik (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Uwe Scheuermann	

4	Module coordinator	Prof. Dr. Uwe Scheuermann
5	Contents	Die Vorlesung gibt einen Überblick über die wichtigsten Grundlagen der Aufbau- und Verbindungstechnik in der Leistungselektronik. Sie soll künftige Entwickler und Anwender von Leistungsmodulen mit den grundlegenden Konzepten vertraut machen. Hierbei werden Grundkenntnisse über leistungselektronische Bauelemente und Grundschaltungen vorausgesetzt, wie sie in der Vorlesung "Leistungselektronik" vermittelt werden. Die Vorlesung wird von einem Vertreter der Industrie gehalten, der durch seine langjährige Tätigkeit in der Entwicklung und Qualifizierung von Leistungsmodulen einen reichen Erfahrungsschatz einbringt. Der Dozent ist somit in der Lage, die vorgestellten theoretischen Zusammenhänge durch praxisnahe Beispiele zu veranschaulichen. 1. Einführung • Aufgaben der Aufbau- und Verbindungstechnik • Grundstruktur eines Leistungsmoduls • Verlustleistung 2. Thermische Grundlagen • Mechanismen der Wärmeableitung • Analogien zwischen thermischer und elektrischer Leitung • Thermische Ersatzschaltbilder 3. Thermische Messverfahren • Messung durch Kontaktsensoren • Berührungslose Messverfahren • Das Leistungsbauelement als Sensor 4. Materialien in der Aufbau- und Verbindungstechnik • Elektrisch leitfähige Materialien • Elektrisch isolierende Materialien • Gehäusewerkstoffe und Silikone 5. Verbindungstechnologien • Löten oder Kleben • Drahtbonden • Druckkontakttechnik • Federkontakte 6. Parasitäre Effekte • Parasitärer elektrischer Widerstand • Parasitäre Kapazitäten • Parasitäre Induktivitäten 7. Zuverlässigkeit • Bauelementbezogene Prüfungen • Gehäusebezogene Prüfungen • Lebensdauerrelevante Prüfungen

		8. Bauformen von Leistungsmodulen • Monolithisch integrierte Systeme • Bauformen für die Leiterplattenmontage • Klassische Module mit Grundplatte • Module ohne Grundplatte • Architekturen in Druckkontakttechnik • Systemintegration für hohe Leistungen 9. Datenblätter • Elektrische Kenngrößen • Grenzwerte der Belastung • Isolationskoordination 10. Systemaufbau • Kühlkörper • Thermische Koppelmedien • Parallelschaltung 11. Fehler- und Ausfallanalyse • Thermische Überlastung • Zerstörung durch Überspannung • Höhenstrahlung • Korrosion durch Umwelteinflüsse 12. Entwicklungstendenzen und Herausforderungen • Erhöhung der maximal zulässigen Sperrschichttemperatur • Synergien durch Systemintegration • Kandidaten für eine zuverlässigere Verbindungstechnik
6	Learning objectives and skills	Die Studierenden • verstehen die grundlegenden Funktionen der Aufbau- und Verbindungstechnik für leistungselektronische Komponenten, • identifizieren die wichtigsten Eigenschaften der beim Aufbau verwendeten Materialien, • erklären die Funktion von klassischen und fortschrittlichen Verbindungsverfahren, • berechnen das thermische Verhalten eines Leistungsmoduls mit Hilfe von thermischen Ersatzschaltbildern, • analysieren unterschiedliche Moduldesigns hinsichtlich ihrer thermischen und parasitären elektrischen Eigenschaften, • bewerten verschiedene Bauformen leistungselektronischer Module hinsichtlich ihrer Vor- und Nachteile für spezifische Anwendungsanforderungen
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral Mündliche Prüfung, 30min
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester

13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	Dierk Schröder: Leistungselektronische Bauelemente, 2.Auflage, Springer, Berlin, 2006. (Kapitel 10, S. 706-772) Josef Lutz: Halbleiter-Leistungsbaulemente, Springer, Berlin, 2006. (Kapitel 4-7, S. 269 ff) Peter R. W. Martin (Hrsg.): Application manual power modules, ISLE, Ilmenau, 2000.

1	Module name 123620	Elektrische Bahnen Electrical railways	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr. Matthias Hofstetter
5	Contents	Ziel Die Studierenden sind nach der Teilnahme an der Veranstaltung in der Lage, • den Einfluss der Einsatzbedingungen Elektrischer Bahnen auf die Auslegung der Antriebstechnik (Traktion) zu bewerten, • das komplexe Zusammenspiel zwischen elektrischen, elektromechanischen und mechanischen Komponenten in Straßen- und Stadtbahnen, U-Bahnen, Vollbahnen zu analysieren und zu bewerten, • einfache Dimensionierungen von Triebfahrzeugen aus Zugkraft-/Geschwindigkeitsanforderungen zu entwickeln, • die Steuerung von Fahrmotoren sowie die Erzeugung und Übertragung von Zugkraft zu analysieren, • sowie die historische Entwicklung, die verkehrstechnischen Aspekte der Zugförderung, die Geräte der Stromrichtertechnik, die Energieversorgungssysteme der Bahnen und das Gebiet der "unkonventionellen" Bahnen zu erinnern. Inhalt: Historischer Überblick, elektrische Zugförderung, Vorteile elektrischer Zugförderung, verkehrstechnische Unterteilung der Bahnen, Energieversorgungssysteme der Bahnen, Dimensionierung von Triebfahrzeugen, Übertragung der Zugkraft, Fahrmotoren, Gleichstrom-Reihenschlußmotor, Einphasenwechselstrom-Kommutatormotor, Asynchronmotor, Antriebe, Getriebe, Kopplung Antrieb-Fahrzeug, Steuerung der Fahrmotoren, Fahrmotorsteuerung bei Gleichstrombahnen, Fahrmotorsteuerung bei Wechselstrombahnen, Umrichter, Drehstromantriebstechnik, Kompatibilität, Geräte der Stromrichtertechnik, Stromabnehmer, Hauptschalter, Hilfsbetriebe, Fahrzeuge, Straßen- und Stadtbahnen, U-Bahnen, Vollbahnen.
6	Learning objectives and skills	Nach der Teilnahme an dieser Vorlesung sind die Studierenden in der Lage, • die allgemeine Theorie der Leistungselektronik und der elektrischen Antriebstechnik auf die Dimensionierung von Triebfahrzeugen elektrischer Bahnen anzuwenden, • das erlangte Wissen auf Aspekte der Automobil-Elektromobilität zu übertragen, • das gewonnene Verständnis für Unternehmerische Strategien mit den zugehörigen Investitionsentscheidungen sowie die Betrachtung von Produktkosten im Lebenszyklus zu erinnern,

		• basierend auf dem historischen Abriss die heutigen Technologie Chancen bzgl. ihrem Innovationspotenzial am Markt zu beurteilen, • die erworbene Kenntnis vom komplexen Zusammenwirken der Subsystemen, der regionalen Entstehung von Normen und dem heutiger Handlungsbedarf bzgl. deren Harmonisierung zu berücksichtigen • sowie die Lernziele bei einer zugehörigen Werksführung zu festigen und zu vertiefen.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	Z. Filipovic: Elektrische Bahnen, Springer-Verlag

1	Module name 145947	Hochfrequenzmesstechnik Microwave Measurements	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Martin Vossiek
5	Contents	Die Hochfrequenzmesstechnik hat für die Tätigkeiten in der Forschung, Entwicklung und Fertigung eine ganz besondere Bedeutung. Sie dient der Verifikation von Praxis und Theorie bei der Entwicklung neuer Funk-, Radar- und Drahtlosgeräten und Verfahren sowie bei der Einhaltung technischer Parameter während der Fertigung der Geräte. In der Vorlesung in Kombination mit praktischen Übungen werden typische Geräteklassen der HF-Messtechnik, deren Aufbau und Anwendungsgebiete detailliert vorgestellt und Messaufgaben demonstriert.
6	Learning objectives and skills	Fachkompetenz Verstehen Die Lernenden verstehen den Aufbau und die Funktionsweise von typischen Baugruppen in HF-Messgeräten. Sie können das Zusammenwirken der einzelnen Baugruppen beschreiben. Anwenden Die Lernenden können Gerätekonzpte vergleichen und durch Rechnungen abschätzen, welche Anforderungen an Messgeräte durch die jeweilige Messaufgabe gestellt werden. Analysieren Lernende können alternative Gerätekonzpte für eine Messaufgabe differenzieren und gegenüberstellen. Evaluieren (Beurteilen) Lernende können aus der Kenntnis der Funktionsweise und des Aufbaus eines Messgeräts unter Berücksichtigung der Messanforderungen HF-Messtechnik evaluieren. Erschaffen Lernende können mit dem vermittelten Wissen Messgeräte konzipieren und unter Anwendung der zugrundeliegenden Theorie Blockschaltbilder für ein Gerätekonzpt erstellen und die Leistungsfähigkeit abschätzen.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral Die Prüfungsleistung ist eine mündliche Prüfung von 30 Minuten Dauer.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester

13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	Thumm, M., Wiesbeck, W., Kern, S.: Hochfrequenzmeßtechnik. B.G. Teubner, Stuttgart, 1997 Schiek, B.: Grundlagen der Hochfrequenz-Messtechnik, Springer-Verlag, Berlin, 1999 Hiebel, M.: Grundlagen der vektoriellen Netzwerkanalyse, München: Rohde & Schwarz GmbH, 2006 Rauscher, Ch.: Grundlagen der Spektrumanalyse, München: Rohde & Schwarz GmbH, 2004 Dunsmore, J.P.: Handbook of Microwave Component Measurements Hoboken, NJ: John Wiley & Sons, 2012 Bonaguide, G.; Jarvis, N.: The VNA Applikation Handbook, Boston, London: Artech House, 2019

1	Module name 179490	Echtzeitsysteme mit erweiterten Übungen Real-time systems with extended exercises	7,5 ECTS
2	Courses / lectures	Übung: Echtzeitsysteme (Rechnerübung) (2 SWS) Vorlesung: Echtzeitsysteme (2 SWS) Übung: Echtzeitsysteme (Erweiterte Übung) (2 SWS)	- - 5 ECTS
3	Lecturers	Eva Dengler Dr.-Ing. Peter Wägemann	

4	Module coordinator	Dr.-Ing. Peter Wägemann	
5	Contents	Videobearbeitung in Echtzeit, Echtzeitstrategiespiel, echtzeitfähig - der Begriff Echtzeit ist wohl einer der am meisten strapazierten Begriffe der Informatik und wird in den verschiedensten Zusammenhängen benutzt. Diese Vorlesung beschäftigt sich mit dem Begriff Echtzeit aus der Sicht von Betriebssystemen - was versteht man eigentlich unter dem Begriff Echtzeit im Betriebssystemumfeld, wo und warum setzt man sog. Echtzeitbetriebssysteme ein und was zeichnet solche Echtzeitbetriebssysteme aus? In dieser Vorlesung geht es darum, die oben genannten Fragen zu beantworten, indem die grundlegenden Techniken und Mechanismen vermittelt werden, die man im Betriebssystemumfeld verwendet, um Echtzeitsysteme und Echtzeitbetriebssysteme zu realisieren. Im Rahmen dieser Vorlesung werden unter anderem folgende Themen behandelt: • zeitgesteuerte und ereignisgesteuerte Systeme • statische und dynamische Ablaufplanungsverfahren • Fadensynchronisation in Echtzeitbetriebssystemen • Behandlung von periodischen und nicht-periodischen Ereignissen In den begleitenden Übungen werden die in der Vorlesung vorgestellten Techniken bei der Entwicklung eines kleinen Echtzeitsystems praktisch umgesetzt.	
6	Learning objectives and skills	Studierende, die das Modul erfolgreich abgeschlossen haben: • unterscheiden die verschiedenen Komponenten eines Echtzeitsystems. • bewerten die Verbindlichkeiten von Terminvorgaben (weich, fest, hart). • erläutern die Zusammensetzung des Laufzeitverhaltes einer Echtzeitanwendung. • klassifizieren die Berührungspunkte zwischen physikalischem Objekt und kontrollierendem Echtzeitsystem. • interpretieren die Zeitparameter des durch das Echtzeitrechensystem zu kontrollierenden Objekts. • nennen die Zeitparameter des zugrundeliegenden Rechensystems (Unterbrechungslatenz, Ausführungszeit, ...). • unterscheiden synchrone und asynchrone Programmunterbrechung (insbesondere Trap/Interrupt, Ausnahmebehandlung und Zustandssicherung).	

- skizzieren die Verwaltungsgemeinkosten des schlimmsten Falls.
- entwickeln in der Programmiersprache C und wenden die GNU Werkzeugkette für den ARM Cortex M4 an.
- erstellen Echtzeitanwendungen auf Basis der eCos OS-Schnittstelle
- ordnen die Strukturelemente von Echtzeitanwendungen zu: Aufgabe, Arbeitsauftrag und Faden.
- erläutern die Implikationen von zeitlichem Mehrfachbetrieb auf die Verwaltungsgemeinkosten.
- unterscheiden die Umsetzungsalternativen zur Ablaufsteuerung und die Trennung der Belange in Einplanung (Strategie) und Einlastung (Mechanismus).
- benennen die grundsätzliche Verfahren der Ablaufsteuerung (taktgesteuert, reihum, vorranggesteuert).
- erklären die grundlegenden Zeitparameter einer Aufgabe (Auslösezeitpunkt, Termin, Antwortzeit, Latenz, Ausführungszeit, Schlupfzeit).
- unterscheiden die Grundlagen der Planbarkeit (gültig vs. zulässig, Optimalität von Einplanungsalgorithmen).
- beschreiben den Unterschied zwischen konstruktiver und analytischer Einhaltung von Terminen-.
- vergleiche die Möglichkeiten (statisch, dynamisch) der zeitliche Analyse von Echtzeitanwendungen.
- erklären die Grundlagen und Beschränkungen von dynamischer (worst-case?) und statischer WCET-Analyse (makroskopisch und mikroskopisch).
- illustrieren Lösungsverfahren zur Bestimmung des längsten Ausführungspfads (Timing Schema, IPET).
- erstellen Zeitmessung mittels Zeitgeber / Oszilloskop und bestimmen den längsten Pfad durch Code-Review.
- erproben und konzipieren werkzeuggestützte WCET-Analyse mittels des absint aiT Analysewerkzeugs.
- Entwickeln und annotieren Flußrestriktionen für die statische WCET-Analyse.
- beschreiben die Grundlagen der Abfertigung periodischer Echtzeitsysteme (Periode, Phase, Hyperperiode).
- skizzieren das periodische Modell und dessen Folgen (Entwicklungskomfort vs. Analysierbarkeit).
- erklären die ereignisgesteuerte Ausführung (feste und dynamische Priorität, Verdrängbarkeit) mittels ereignisorientierter Planer (Berechnungskomplexität, MLQ-Scheduler, O(1)-Scheduler).
- unterscheiden die zeitgesteuerte Ausführung (Busy Loop, Ablaufplan) und die Abfertigung von Arbeitsaufträgen im Abfrage- bzw. Unterbrecherbetrieb.
- wenden die Grundlagen der ereignisgesteuerten Ablaufplanung periodischer Echtzeitsysteme an.

- unterscheiden Verfahren zur statischen (RM, DM) und dynamischen Prioritätsvergabe (EDF, LRT, LST).
- nennen den Unterschied zwischen Anwendungs- und Systemebene (Mehrdeutigkeit von Prioritäten).
- erläutern den Optimalitätsnachweis des RM-, DM- und EDF-Algorithmus und dessen Ausnahmen.
- beschreiben grundlegende Verfahren zur Planbarkeitsanalyse (CPU-Auslastung, Antwortzeitanalyse).
- implementieren komplexe Aufgabensysteme in eCos.
- unterscheiden die Grundlagen der zeitgesteuerten Ablaufplanung periodischer Echtzeitsysteme.
- erstellen regelmäßige, zyklische Ablaufpläne (cyclic executive model, Rahmen).
- vergleiche Methoden der manuellen und algorithmischen Ablaufplanung.
- unterscheiden optimale von heuristischen Verfahren (List Scheduling, Branch & Bound).
- diskutieren die Konsequenzen eines Betriebswechsels in Echtzeitsystemen.
- erstellen takt- beziehungsweise ereignisgesteuerte Abläufe in eCos beziehungsweise tt-eCos.
- entwickeln ein softwarebasiertes Oszilloskop und erstellen dessen zeitliche Analyse und Ablaufplanung.
- klassifizieren die Grundlagen der Abfertigung nicht-periodischer Echtzeitsysteme (minimale Zwischenankunftszeit).
- definieren die Verbindlichkeiten von nicht-periodischen Aufgaben (aperiodisch, sporadisch)
- zeigen die sich ergebenden Restriktionen des periodischen Modells (Mischbetrieb, Prioritätswarteschlangen, Übernahmeprüfung) auf.
- beschreiben die Basistechniken des Laufzeitsystems (Zusteller, Unterbrecherbetrieb, Hintergrundbetrieb).
- quantifizieren die Eigenschaften und Auswirkungen auf den periodischen Teil des Echtzeitsystems.
- formulieren die Grundlagen des Slack-Stealing.
- beschreiben den Einsatz von bandweite-bewahrenden Zustellern.
- unterscheiden aufschiebbare Zusteller und Sporadic Server (SpSL und POSIX).
- wenden eine Übernahmeprüfung bei sporadischen Aufgaben mittels dichte- oder schlupfbasierten Akzeptanztests an.
- arbeiten einen strukturierter Ablaufplan (Rahmen) aus und untersuchen den Einsatz von Slack-Stealing.
- ermitteln gerichtete Abhängigkeiten und Rangfolgen in Echtzeitanwendungen (Abhängigkeits- und Aufgabengraph).
- stellen Umsetzungsalternativen für Abhängigkeiten einander gegenüber (naiv, implizit, explizit).

		• beschreiben das Konzept der zeitlichen Domänen und physikalischer bzw. logischer Ereignisse. • übertragen Abhängigkeiten auf das Problem der Ablaufplanung (modifiziere Auslöszeitpunkt/Termin, Phasenversatz). • konzipieren Rangfolge und aperiodische Steuerung in eCos. • implementieren einen aperiodischer Moduswechsel mit Zustandsüberführung in eCos. • gestalten einen Signal-Trigger für das entwickelte softwarebasierten Oszilloskops. • konzipieren explizite Synchronisation mittels Nachrichten in eCos. • wenden die Grundlagen von Wettstreit um Betriebsmitteln, Konkurrenz und Konfliktsituationen (kritische Abschnitte, (un)kontrollierte Prioritätsumkehr) an. • beschreiben echtzeitfähige Synchronisationsprotokolle (NPCS, PI, PCP). • nennen die Vor- und Nachteile der Techniken (transitive Blockung, Verklemmungen). • hinterfragen die Vereinfachung des PCP durch stapelbezogene Grenzprioritäten. • bestimmen die Ablaufplanung unter Berücksichtigung von Blockierungszeiten und Selbstsuspendierung. • implementieren Zugriffskontrolle (NPCS, PI, PCP) in Echtzeitanwendungen mit eCos. • analysieren Blockade für die Zugriffskontrolle in eCos. • erläutern die Anforderungen an verteilte Echtzeitsysteme (Komposition, Erweiterbarkeit, Komplexität, Ereignis- vs. Zustandsnachricht). • fassen die Grundlagen von Knoten, Netzwerkschnittstellen und Netzübergängen sowie die Konzepte der expliziten und impliziten Flusskontrolle zusammen. • erschließen sich typische Probleme (zeitliche Analyse, Beobachtbarkeit, Synchronisation, Rangfolge) und Fehlerquellen bei der Programmierung von Echtzeitanwendungen. • können in Gruppen kooperativ und effektiv arbeiten. • können ihre Entwurfs- und Implementierungsentscheidungen kompakt präsentieren und argumentativ vertreten. • reflektieren ihre Entscheidungen kritisch und leiten Alternativen ab. • können offen und konstruktiv mit Schwachpunkten in der Konzeption wie Umsetzung umgehen.
7	Prerequisites	Für eine erfolgreiche Teilnahme an der Veranstaltung sind grundlegende Programmierkenntnisse in C/C++ erforderlich. Diese können durch den (empfohlenen) Besuch entsprechender Grundlagenveranstaltungen oder im Eigenstudium erworben sein, eine formale Voraussetzung besteht in diesem Zusammenhang nicht.

8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Portfolio 30-minütige mündliche Prüfung über den gesamten Stoff der Veranstaltung. Teilnahme an den Übungen und die Bearbeitung aller Übungsaufgaben wird hierzu dringend empfohlen!
11	Grading procedure	Portfolio (100%) Die Modulnote ergibt sich aus der 30-minütigen mündlichen Prüfung.
12	Module frequency	Irregular
13	Workload in clock hours	Contact hours: 90 h Independent study: 135 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	• Hermann Kopetz. Real-Time Systems: Design Principles for Distributed Embedded Applications. Kluwer Academic Publishers, 1997. • Jane W. S. Liu. Real-Time Systems. Prentice-Hall, Inc., 2000. • Wolfgang Schröder-Preikschat. System-programmierung. Vorlesungsfolien. 2006.

1	Module name 244966	Zuverlässigkeit technischer Systeme Reliability of technical systems	5 ECTS
2	Courses / lectures	Übung: Übungen zu Zuverlässigkeit technischer Systeme (2 SWS) Vorlesung: Zuverlässigkeit technischer Systeme (2 SWS)	- 5 ECTS
3	Lecturers	Tobias Rumpel Prof. Dr.-Ing. Sebastian Sattler	

4	Module coordinator	Peter Meisel Prof. Dr.-Ing. Sebastian Sattler
5	Contents	Die Vorlesung behandelt Methoden zur konsistenten Darstellung von zuverlässigen, rückwirkenden, digitalen Systemen. Mit Hilfe von Aussagen wird in mathematische Formalismen für den automatenorientierten Entwurf digitaler Systeme eingeführt. Spezielle Themen aus dem Bereich der durchgängigen Spezifikation allgemeiner technischer Systeme werden diskutiert. • Motivation • Aussagen • Spezifikation • Multi-Set • Komplementärlogik, Limesdiagramm • Automat • Modellierung
6	Learning objectives and skills	Fachkompetenz Verstehen • Die Studierenden können die Methoden zur konsistenten Darstellung von zuverlässigen, rückwirkenden, digitalen Systemen darlegen • Die Studierenden können die mathematischen Formalismen für den automatenorientierten Entwurf digitaler Systeme beurteilen • Die Studierenden können den Entwurf von asynchronen digitalen Automaten nachvollziehen und Analysieren Evaluieren (beurteilen) • Die Studierenden können die Methoden zur Darstellung von Automaten beschreiben und erkennen die verschiedenen Automatentypen Erschaffen • Die Studierenden können einen Automaten nach einer vorgegebenen Spezifikation erstellen
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination

11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 250058	Signal Analysis Signal analysis	2,5 ECTS
2	Courses / lectures	Vorlesung: Signalanalyse (2 SWS)	-
3	Lecturers	Dr.-Ing. Heinrich Löllmann	

4	Module coordinator	Dr.-Ing. Heinrich Löllmann
5	Contents	Es werden im Rahmen dieser Vorlesung unterschiedliche Verfahren zur Analyse digitaler Signale, sowie deren Anwendungsmöglichkeiten behandelt. Die folgenden Konzepte werden dabei insbesondere behandelt: • Fourieranalyse von Signalen • Signalanalyse mittels Zeit-Frequenz-Transformationen • Parametrische und nichtparametrische Signalanalyse • Verfahren zur Frequenzschätzung • Räumliche Signalanalyse • Filterbänke und Wavelets. In this course, different approaches for the analysis of digital signals and their applications are treated, which comprises the following topics: • Fourier analysis of signals • Signal analysis by means of time-frequency transformations • Parametric and non-parametric signal analysis • Frequency estimation • Spatial signal analysis • Filter-banks and wavelets.
6	Learning objectives and skills	Die Studierenden • beschreiben, welche Methoden der Signalanalyse für unterschiedlichen Arten von Signalen angewendet werden • beschreiben grundlegende Methoden der spektralen Signalanalyse • erläutern wodurch die spektrale und zeitliche Auflösung bei der Spektralanalyse von Signalen begrenzt wird • beschreiben die Konzepte sowie die Vor- und Nachteile der parametrischen und nichtparametrischen Signalanalyse • erklären unterschiedliche Verfahren der Zeit-Frequenz-Analyse • stellen die Analyse von Signalen mittels Filterbänke und Wavelets dar • können Verfahren zur Frequenzschätzung erläutern • formulieren Verfahren zur Analyse räumlicher Signale. The students • describe which methods for signal analysis can be applied for different types of signals • describe fundamental approaches for spectral signal analysis • explain the limiting factors for the time and frequency resolution for the spectral analysis of signals • describe concepts as well as the pros and cons of parametric and non-parametric signal analysis • explain different approaches for time-frequency analysis

		• describe the analysis of signals by means of filter-banks and wavelets • explain methods for frequency estimation • formulate approaches for spatial signal analysis.
7	Prerequisites	Fundierte Kenntnisse in digitaler Signalverarbeitung. Requirements Solid knowledge in digital signal processing
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral Mündliche Prüfung mit einer Dauer von 30 min. Oral examination of 30 min duration.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	P. Stoica und R. Moses: "Spectral Analysis of Signals", Pearson Prentice Hall, 2005

1	Module name 432733	Regelung im Antriebsstrang von Kraftfahrzeugen Control of vehicle powertrains	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr.-Ing. Andreas Michalka	
5	Contents	Der Antriebsstrang von Kraftfahrzeugen enthält die Komponenten, die zur Erzeugung, Übertragung und Verteilung der mechanischen Antriebsleistung dienen, z.B. Verbrennungsmotor, E-Maschinen und Getriebe. Der Betrieb dieser Komponenten erfolgt durch elektronische Steuergeräte, wobei in Hard- und Software viele Regelungen implementiert werden: Von der Automatisierung zahlreicher einzelner Aktoren über die Einstellung der Abgasqualität (Lambda-Regelung) bis hin zur Laufruheregelung von Verbrennungsmotoren. Der Inhalt gliedert sich in folgende Abschnitte: 1. Mathematische Modellierung des Fahrzeugs, des Antriebsstrangs und dessen Komponenten als Basis für Simulation und Regelungsentwurf 2. Regelsysteme auf Ebene der Antriebsstrangkomponenten 3. Längsdynamiksteuerung für Kraftfahrzeuge 4. Regelsysteme für Längsführung Sie richtet sich an Studierende, die sich für den Entwurf und die Implementierung von Regelungen am praktischen Beispiel "Antriebsstrang" interessieren.	
6	Learning objectives and skills	Die Studierenden: • kennen die Komponenten konventioneller und hybrider Antriebsstränge und erklären deren Funktion • diskutieren mathematische Modelle dieser Komponenten, des Antriebsstrangs und der Fahrzeuglängsbewegung als Basis für Simulation und Regelungsentwurf • kennen Regelsysteme auf Ebene der Antriebsstrangkomponenten und erläutern deren Arbeitsweise • erklären das Konzept der Längsdynamiksteuerung für Kraftfahrzeuge • kennen Regelsysteme für die Längsführung und erläutern deren Arbeitsweise	
7	Prerequisites	Die Vorlesungen "Regelungstechnik A" und "Regelungstechnik B" oder "Einführung in die Regelungstechnik" werden dringend empfohlen.	
8	Integration in curriculum	no Integration in curriculum available!	
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242	
10	Method of examination	Oral mündlich, 30 Minuten	
11	Grading procedure	Oral (100%)	

12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 498723	Transformationen in der Signalverarbeitung Transforms in signal processing	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	PD Dr.-Ing. Jürgen Seiler
5	Contents	Das Modul "Transformationen in der Signalverarbeitung" behandelt mehrere verschiedene Transformationen, die im Rahmen der Signalverarbeitung Verwendung finden. Dabei werden zuerst die grundlegenden Konzepte von Transformationen diskutiert und die Vorteile die Transformationen mit sich bringen erläutert. Im Anschluss daran werden die grundlegenden Eigenschaften von Integraltransformationen betrachtet und die Laplace- und die Fourier-Transformation im Detail untersucht. Um auch zeitlich veränderliche Signale gut transformieren zu können werden danach die Kurzzeit-Fourier-Transformation und die Gabor-Transformation eingeführt. Im Anschluss daran erfolgt eine Betrachtung der Auswirkung der Abtastung auf transformierte Signale, bevor die z-Transformation als Transformation für diskrete Signale behandelt wird. Abschließend erfolgt die Betrachtung weiterer Transformationen für diskrete Signale wie der Diskreten Fourier-Transformation oder linearer Block-Transformationen. The module "Transforms in Signal Processing" covers several different transforms which are used in the field of signal processing. For this, first the basic concepts of transforms are discussed and the advantages which are offered by the different transforms are presented. Subsequent to this, fundamental properties of integral transforms are considered and the Laplace- and the Fourier-Transform are examined in detail. To be able to transform time-varying signals, the Short-Time Fourier-Transform and the Gabor-Transform are introduced, afterwards. Subsequent to this, the impact of sampling on transformed signals is analyzed before the z-Transform as a transform for discrete signals is covered. Finally, further transforms for discrete signals like the Discrete Fourier-Transform or Linear-Block Transforms are discussed.
6	Learning objectives and skills	Die Studierenden können nach Besuch der Vorlesung • Anwendungsmöglichkeiten von Transformationen bestimmen • Integraltransformationen gegenüberstellen und untersuchen • die Existenz von Transformationen hinterfragen • die Eindeutigkeit von Transformationen überprüfen • Sätze und Eigenschaften von Transformationen entwickeln • zu Transformationen zugehörige inverse Transformationen einschätzen • die Zusammenhänge zwischen verschiedenen Transformationen einschätzen • auf Zusammenhänge zwischen Ausgangssignalen und transformierten Signalen folgern • Symmetriebeziehungen von Transformationen ausarbeiten

		• Zusammenhänge zwischen kontinuierlichen und diskreten Signalen ausarbeiten Educational Objectives and Competences: After attending the lecture, students will be able to • determine applications of transforms • contrast and examine integral transforms • question the existence of transforms • evaluate the uniqueness of transforms • develop theorems and properties of transforms • evaluate to transforms corresponding inverse transforms • evaluate the relationships between different transforms • assess the relationship between original signal and transformed signals • devise the symmetry properties of transforms • devise the relationship between continuous and discrete signals
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral Mündliche Prüfung von 30 min Dauer.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	K. Krüger, Transformationen - Grundlagen und Anwendungen in der Nachrichtentechnik, Vieweg Verlag, Braunschweig B. Girod, R. Rabenstein, A. Stenger, Einführung in die Systemtheorie, B. G. Teubner Verlag, Stuttgart

1	Module name 542026	Testfreundlicher Schaltungsentwurf Design-for-Test	2,5 ECTS
2	Courses / lectures	Vorlesung: Testfreundlicher Schaltungsentwurf (Design-for-Test) (2 SWS)	2,5 ECTS
3	Lecturers	Dr. Jürgen Alt	

4	Module coordinator	Dr. Jürgen Alt Peter Meisel
5	Contents	Diese Vorlesung vermittelt die Grundlagen des Testfreundlichen Schaltungsentwurfs (Design-for-Test). Schwerpunkte hierbei sind digitale Schaltungselemente mit detaillierten Darstellungen zu: • Fehlermodellierung • Prüfbus (Scan Design) • Eingebauter Selbsttest (Built-In Self-Test) • Allgemeine Testbarkeitsprobleme Als generelle Prinzipien, die auch für andere technische Disziplinen gültig sind, werden im Rahmen der Vorlesung herausgearbeitet: • Komplexität und ihre Beherrschung • Strukturierte und funktionsorientierte Methoden • Optimierungen im Entwicklungsprozess und ihre Abhängigkeit von Marktsegmenten
6	Learning objectives and skills	Verstehen • Die Studierenden verstehen die wirtschaftliche Bedeutung von Test und Testbarkeit • Die Studierenden erlernen die grundlegenden Schaltungen und Methoden zum testfreundlichen Schaltungsentwurf Analysieren • Die Studierenden charakterisieren in Systemstudien die jeweils eingesetzten Testmethoden • Die Studierenden erklären die Vorgehensweise beim Test von Analog- und Hochfrequenzmodulen • Die Studierenden erschließen den Einfluss der Komplexität auf die Lösung technischer Probleme Evaluieren (Beurteilen) • Die Studierenden beurteilen die Bedeutung von Standards an Beispielen • Die Studierenden vergleichen notwendige Optimierungen im Entwicklungsprozess in Abhängigkeit von Marktsegmenten
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h

		Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 800224	Medical Imaging System Technology Medical imaging systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr. Wilhelm Dürr
5	Contents	Röntgens Entdeckung "einer neuen Art von Strahlen" im Jahr 1885 war der Beginn der teilweise spektakulären Entwicklung der bildgebenden medizinischen Diagnostik. Neue Erkenntnisse und Entwicklungen, insbesondere in der Physik, führten zu konsequenten Anwendungen im Bereich der Medizin. So entstanden die folgenden (bedeutendsten) bildgebenden Verfahren: Röntgen, nuklearmedizinische Bildgebung, Sonographie, Röntgen-Computer-Tomographie und Magnetresonanztomographie. Nach einem Überblick zur historischen Entwicklung und zu den erforderlichen physikalischen und systemtheoretischen Grundlagen werden die einzelnen Verfahren vorgestellt. Neben der Erläuterung des Funktionsprinzips liegt jeweils der Schwerpunkt bei der technischen Umsetzung. Biologische, physikalische und technische Grenzen werden aufgezeigt. Anhand von Applikationsbeispielen wird das heute Mögliche dargestellt. Contents Röntgen's discovery of "a new kind of ray" about 100 years ago was the beginning of the partially spectacular development of imaging systems for medical diagnosis. New knowledge and developments, especially in physics, led to consequent applications in the area of medicine. Over time, there developed the following (most significant) medical imaging techniques: roentgenography, nuclear medical imaging, sonography, X-ray computer tomography and magnetic resonance tomography. After an overview of the historical developments and some basic physics concerning radiation and dose, the individual techniques of the imaging modalities will be discussed in detail. Following the description of the functional principles, the point of concentration will lie in the technical realization. Biological, physical and technical limits are to be described. What is possible today is to be shown through examples in application.
6	Learning objectives and skills	Die Studierenden • kennen die technischen und physikalischen Grundlagen von Röntgengeräten, nuklearmedizinische Bildgebung, Sonographie, Röntgen-Computer-Tomographie und Magnetresonanztomographie. • verstehen den Aufbau und Funktion bildgebender Verfahren der Medizintechnik und können diese beschreiben und erläutern. • vergleichen Möglichkeiten und diskutieren Vor- und Nachteile verschiedener bildgebender Verfahren je nach medizinischer Applikation. Learning Goals

		Students • know the basics of physics and technology of X-ray systems, nuclear medical imaging, sonography, X-ray computer tomography and magnetic resonance technology • can describe and explain the functioning of medical imaging systems • are familiar with the application spectrum and can discuss advantages and disadvantages of the various modalities.
7	Prerequisites	Basic knowledge in these fields is recommended: • Principles of medical imaging systems • Electromagnetic fields • Electric and acoustic wave propagation • Experimental physics
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Fercher, A.F.: Medizinische Physik. Springer-Verlag, 1992 Oppelt, A. (Ed.), Imaging Systems for Medical Diagnostics. Publicis 2005 Rosenbusch, G., Oudkerk, M., Amman, E.: Radiologie in der medizinischen Diagnostik. Blackwell Wissenschafts-Verlag, Berlin 1994

1	Module name 858896	Modellierung, Optimierung und Simulation von Energiesystemen Modeling, optimization and simulation of energy systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Marco Pruckner
5	Contents	In der Vorlesung Modellierung, Optimierung und Simulation von Energiesystemen werden systemtechnische Planungs- und Analysemethoden behandelt, die zur Lösung komplexer und interdisziplinärer Entscheidungsaufgaben in der Energiewirtschaft eingesetzt werden. Dabei werden die wichtigsten Methoden und Verfahren anhand praktischer Fragestellungen (z.B. Ausbau erneuerbarer Energien, Zunahme der Elektromobilität) aus der energiepolitischen Planung vermittelt und die Bewältigung technisch-ökonomischer Probleme verdeutlicht. Zu den eingesetzten Tools zählen die Statistiksoftware R, AnyLogic und IpSolve. Vorkenntnisse im Umgang mit diesen Werkzeugen ist nicht zwingend erforderlich. In den Übungen werden Einführungen in die genannten Softwarepakete gegeben.
6	Learning objectives and skills	Die Studierenden • unterscheiden Probleme und Herausforderungen, die mit dem Energieumstieg verbunden sind, • erfassen die Vorteile und die Anwendungsmöglichkeiten computergestützter Planungsmethoden im Energiebereich, • analysieren verschiedene Problemstellungen und setzen Lösungen dafür um, • erlernen verschiedene Methoden der Datenanalyse, Optimierung und Simulation.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Portfolio
11	Grading procedure	Portfolio (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german german or english
16	Bibliography	

1	Module name 876012	Verlässliche Echtzeitsysteme (Vorlesung mit Übungen) Dependable real-time systems (lecture with exercises)	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr.-Ing. Peter Wägemann
5	Contents	Viele Echtzeitsysteme sind in Bereiche des täglichen Lebens eingebettete, die hohe Anforderungen an die funktionale Sicherheit dieser Systeme stellen. Beispiele hierfür sind Fahrerassistenzsysteme in modernen Automobilen, medizinische Geräte, Prozessanlagen in Kernkraftwerken oder Chemiefabriken oder Flugzeuge. Fehlfunktionen in diesen Anwendungen ziehen mitunter katastrophale Konsequenzen nach sich - Menschen können ernsthaft verletzt oder sogar getötet werden, Landstriche können unbewohnbar gemacht oder zumindest großer finanzieller Schaden verursacht werden. Dieses Modul betrachtet Methoden und Werkzeuge, die uns helfen können, einerseits *zuverlässig Software zu entwickeln* (also Fehler im Programm zu entdecken und zu vermeiden), und andererseits *zuverlässige Software zu entwickeln* (also Abstraktionen, die auch im Fehlerfall ihre Gültigkeit behalten). Hierbei steht weniger die Vermittlung theoretischer Grundkenntnisse auf diesen Gebieten im Vordergrund, also vielmehr • die praktische Anwendung existierende Werkzeuge und Methoden • sowie die Erfahrung und das Verständnis ihrer Grenzen. Auf diese Weise soll ein Fundament für die konstruktive Umsetzung verlässlicher Echtzeitsysteme gelegt werden. Dieses Modul soll daher fundierte Anknüpfungspunkte für die Entwicklung verlässlicher Echtzeitsysteme vermitteln, die Ad-hoc-Techniken möglichst ersetzen sollen.
6	Learning objectives and skills	Studierende, die das Modul erfolgreich abgeschlossen haben: • nennen die Konzepte und die Taxonomie verlässlicher Systeme, unterscheiden Software- und Hardwarefehler und klassifizieren Fehler (Defekt, Fehler, Fehlverhalten). • stellen Fehlerbäume auf. • organisieren Softwareentwicklungsprojekte mittels der Versionsverwaltung git. • vergleichen die verschiedenen Arten der Redundanz als Grundvoraussetzung für Fehlererkennung und -toleranz. • entwickeln fehlertolerante Systeme mittels Replikation. • diskutieren die Fehlerhypothese und die Sicherstellung von Replikdeterminismus. • erläutern die Vor- und Nachteile softwarebasierter Replikation und den Einsatz von Diversität.

- wenden Informationsredundanz zur Härtung von Daten- und Kontrollflüssen an.
- bewerten die Effektivität der arithmetischer Codierung von Programmen und verallgemeinern diesen Ansatz auf die verschiedenen Implementierungsebenen (Maschinenprogramm zu Prozessinkarnation).
- interpretieren den Einfluss der Ausführungsplattform (Hardware, Betriebssystem) auf die Leistungsfähigkeit der Fehlererkennung.
- konzipieren eine fehlertolerante Ausführungsumgebung für ein softwarebasiertes TMR-System basierend auf ANBD-Codierung.
- nennen die Grundlagen der systematischen Fehlerinjektion.
- überprüfen die Wirksamkeit von Fehlertoleranzmechanismen mittels Fehlerinjektion auf der Befehlssatzebene.
- entwickeln Testfälle für die Fehlerinjektion mittels des fail** Werkzeugs.
- setzen Messergebnisse in Relation zu dem tatsächlichen Fehlerraum.
- beschreiben die Grundlagen der Fehlererholung (Vorwärts- bzw. Rückwärtskorrektur) und Reintegration fehlgeschlagener Knoten.
- vergleichen den Zustandstransfer am Beispiel der Running bzw. Recursive State Restoration.
- benennen Konzepte der Rückwärtskorrektur durch Entwurfsalternativen (Recovery Blocks).
- fassen die Grundlagen des dynamischen Testens zusammen.
- unterscheiden Black-Box und White-Box Testverfahren.
- konzipieren und implementieren Testfälle.
- überprüfen die Testüberdeckung anhand grundlegender Überdeckungskriterien (Anweisungs- bis Bedingungsüberdeckung).
- geben die Grundlagen der statischen Programmanalyse wieder.
- nennen die Funktionsweise von Hoare- WP-Kalkül.
- verifizieren eine Ampelsteuerung mittels des FramaC Werkzeugs zur statischen Analyse von C Programmen.
- beschreiben den Korrektheitsnachweis mittels abstrakter Interpretation und unterscheiden die konkrete von der abstrakten Programmsemantik.
- erläutern die Funktionsweise von Sammel- und Präfixsemantiken.
- erstellen einen Korrektheitsbeweis für einen a-b-Filter mittels des Astrée Werkzeugs zur abstrakten Interpretation von C Programmen.
- bewerten die Verlässlichkeit kommerzieller, sicherheitskritischer Systeme anhand von Fallstudien (Sizewell B, Airbus A320).

		• erschließen sich typische Probleme und Fehlerquellen bei der Programmierung von eingebetteten Systemen im Allgemeinen. • klassifizieren Fallstricke und Mehrdeutigkeiten in der Programmiersprache C99 im Besonderen. • können in Gruppen kooperativ und effektiv arbeiten. • können ihre Entwurfs- und Implementierungsentscheidungen kompakt präsentieren und argumentativ vertreten. • reflektieren ihre Entscheidungen kritisch und leiten Alternativen ab. • können offen und konstruktiv mit Schwachpunkten in der Konzeption wie Umsetzung umgehen.
7	Prerequisites	Für eine erfolgreiche Teilnahme an der Veranstaltung sind grundlegende Programmierkenntnisse in C/C++ erforderlich. Diese können durch den (empfohlenen) Besuch entsprechender Grundlagenveranstaltungen oder im Eigenstudium erworben sein. Weiterhin sind grundlegende Kenntnisse über Echtzeitsysteme eine, zum Beispiel durch den Besuch der Veranstaltung "Echtzeitsysteme", empfohlen. Eine formale Voraussetzung besteht in diesem Zusammenhang jedoch nicht.
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Portfolio
11	Grading procedure	Portfolio (100%)
12	Module frequency	Irregular
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 96316	Radar, RFID and Wireless Sensor Systems (RWS) Radar, RFID and wireless sensor systems (RWS)	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Martin Vossiek
5	Contents	Radar, RFID and wireless sensor and wireless locating systems are essential for automotive advanced driver-assistance systems (ADAS), autonomous driving and flying, robotics, industrial automation, logistics and novel human machine interfaces. Further key areas include medical electronics, building technology and cyber-physical systems. The module "Radar, RFID and Wireless Sensors" is an introduction into functional principles, building blocks, hardware and signal processing concepts and applications of modern radar, RFID, wireless sensor and real time locating systems. Covered applications include automotive radar, road and air traffic control systems, as well as robotics, industrial automation and medical technology. RWS is an identical replacement of the former module "Drahtlose Sensoren, Radar- und RFID-Systeme DSR.
6	Learning objectives and skills	The students • learn about the setup, function and application of wireless sensors, Radar and RFID-systems • can analyze, discuss and implement basic components and system structures, signal theory, data processing and use cases • can determine the underlying physical limitations and sources of errors • are able to analyze and create system specifications and can compare and rate the usability of wireless esnsors, Radar and RFID-systems • can create and define independently applications and system designs of RWSs
7	Prerequisites	None
8	Integration in curriculum	semester: 6
9	Module compatibility	Sensing & Perception - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written (90 minutes)
11	Grading procedure	Written (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h

14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Sensors for Ranging and Imaging", Graham Brooker, Scitech Publishing Inc., 2009 Radar mit realer und synthetischer Apertur", H. Klausing, W. Holpp, Oldenbourg, 1999 Praxiswissen Radar und Radarsignalverarbeitung" Albrecht K. Ludloff, 2008 "RFID at ultra and super high frequencies: theory and application Dominique Paret, John Wiley & Sons, 2009. RFID-Handbuch: Grundlagen und praktische Anwendungen von Transpondern, kontaktlosen Chipkarten und NFC", Klaus Finkenzeller, Carl Hanser Verlag, 6. Auflage 2012.

1	Module name 92343	Image, Video, and Multidimensional Signal Processing Image, video, and multidimensional signal processing	5 ECTS
2	Courses / lectures	Vorlesung: Image, Video, and Multidimensional Signal Processing (2 SWS) Übung: Supplements Image, Video, and Multidimensional Signal Processing	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Andre Kaup Katja Kossira	

4	Module coordinator	Prof. Dr.-Ing. Andre Kaup
5	Contents	Punktoperationen Histogrammausgleich, Gamma-Korrektur Binäroperationen Morphologische Filter, Erosion, Dilatation, Opening, Closing Farbräume Trichromat, RGB- Farbraum, HSV-Farbraum Mehrdimensionale Signale und Systeme Theorie mehrdimensionaler Signale und Systeme, Impulsantwort, lineare Bildfilterung, Leistungsspektrum, Wiener Filter Interpolation von Bildsignalen Bilineare Interpolation, Bicubische Interpolation, Spline Interpolation Merkmalsdetektion in Bildern Bildmerkmale, Kantendetektion, Hough Transformation, Harris Ecken Detektor, Texturmerkmale, Grauwertematrix Skalierungsraumdarstellung LoG, DoG, SIFT, SURF Bildabgleich Projektive Abbildungen, Blockabgleich, Optischer Fluss, Merkmalsbasierter Abgleich mittels SIFT und SURF, RANSAC Bildsegmentierung Amplituden Schwellenwertermittlung, K-Means Clustering, Bayes Klassifikation, Regionen-basierte Segmentierung, kombinierte Segmentierung und Bewegungsschätzung, zeitliche Segmentierung von Videos Bildverarbeitung im Transformationsbereich Unitäre Transformation, Karhunen-Loeve Transformation, separable Transformationen, Haar und Hadamard Transformation, DFT, DCT Content: Point operations Histogram equalization, gamma correction

		Binary operations Morphological filters, erosion, dilation, opening, closing Color spaces Trichromacy, red-green-blue color spaces, color representation using hue, saturation and value of intensity Multidimensional signals and systems Theory of multidimensional signals and systems, impulse response, linear image filtering, power spectrum, Wiener filtering Interpolation of image signals Bi-linear interpolation, bi-cubic interpolation, spline interpolation Image feature detection Image features, edge detection, Hough transform, Harris corner detector, texture features, co-occurrence matrix Scale space representation Laplacian of Gaussian, difference of Gaussian, scale invariant feature transform, speeded-up robust feature transform Image matching Projective transforms, block matching, optical flow, feature-based matching using SIFT and SURF, random sample consensus algorithm Image segmentation Amplitude thresholding, k-means clustering, Bayes classification, region-based segmentation, combined segmentation and motion estimation, temporal segmentation of video Transform domain image processing Unitary transform, Karhunen-Loeve transform, separable transform, Haar and Hadamard transform, DFT, DCT
6	Learning objectives and skills	The students • understand point operations for image data and gamma correction • test the effects of rank order and median filters for image data • evaluate and differentiate between different color spaces for image data • explain the principle of two-dimensional linear filtering for image signals • calculate and evaluate the two-dimensional discrete Fourier transform of an image signal • determine enlarged discrete image signals by bi-linear and spline interpolation • verify image data for selected texture, edge and motion features • analyze image and video data for features in different scale spaces • explain and evaluate methods for the matching of image data

		• segment image data by implementing basic classification and clustering methods • understand the principle of transformations on image data and apply them exemplarily
7	Prerequisites	None
8	Integration in curriculum	semester: 5
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• J.-R. Ohm: Multimedia Content Analysis, Springer, 2016 • J. W. Woods: Multidimensional Signal, Image, and Video Processing and Coding, Academic Press, 2nd edition, 2012

1	Module name 96310	Image and Video Compression Image and video compression	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Andre Kaup
5	Contents	Multi-Dimensional Sampling - Sampling theorem revisited, 2D sampling, spatiotemporal sampling, motion in 3D sampling Entropy and Lossless Coding - Entropy and information, variable length codes, Huffman coding, unary coding, Golomb coding, arithmetic coding Statistical Dependency - Joint entropy and statistical dependency, run-length coding, fax compression standards Quantization - Rate distortion theory, scalar quantization, Lloyd-Max quantization, entropy coded scalar quantization, embedded quantization, adaptive quantization, vector quantization Predictive Coding - Lossless predictive coding, optimum 2D linear prediction, JPEG-LS lossless compression standard, differential pulse code modulation (DPCM) Transform Coding - Principle of transform coding, orthonormal transforms, Karhunen-Loève transform, discrete cosine transform, bit allocation, compression artifacts Subband Coding - Principle of subband coding, perfect reconstruction property, discrete wavelet transform, bit allocation for subband coding Visual Perception and Color - Anatomy of the human eye, sensitivity of the human eye, color spaces, color sampling formats Image Coding Standards - JPEG and JPEG2000 Interframe Coding - Interframe prediction, motion compensated prediction, motion estimation, motion compensated hybrid coding Video Coding Standards - H.261, H.263, MPEG-1, MPEG-2 / H.262, H.264 / MPEG-4 AVC, H.265 / MPEG-H HEVC
6	Learning objectives and skills	The students - visualize multi-dimensional sampling and the influence of motion within the video signal - differentiate and evaluate different methods for lossless image and video coding

		• understand and analyze mutual entropy and statistical dependencies in image and video data • determine scalar and vector quantization for different optimization criteria (minimum mean square error, entropy coding, embedded quantization) • determine and evaluate optimal one-dimensional and two-dimensional linear predictor • apply prediction and quantization for a common DPCM system • understand the principle and effects of transform and subband coding for image data including optimal bit allocation • describe the principles of the human visual system for brightness and color • analyze block diagrams and the functioning of hybrid coders and decoders for video signals • know the prevailing international standards of ITU and MPEG for image and video compression.
7	Prerequisites	Lectures on Signal and Systems and Communication Systems strongly recommended
8	Integration in curriculum	semester: 2
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written or oral (90 minutes) Schriftliche Prüfung von 90 min Dauer
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	J.-R. Ohm: Multimedia Communications Technology, Springer, 2004

1	Module name 93173	Computational Visual Perception Computational visual perception	7,5 ECTS
2	Courses / lectures	Vorlesung: Computational Visual Perception (4 SWS) Projektseminar: Tutorials to Computational Visual Perception (2 SWS)	2,5 ECTS 5 ECTS
3	Lecturers	Prof. Dr. Tim Weyrich Prof. Dr. Andreas Kist PD Dr. habil. Patrick Krauß Prof. Dr. Bernhard Egger	

4	Module coordinator	Prof. Dr. Bernhard Egger Prof. Dr. Andreas Kist Prof. Dr.-Ing. Andreas Maier	
5	Contents	How do humans perceive the visual world? How can we build computational models to mimic this human perception? And how can we validate those computational models? This course is designed as an introduction to enable you to build computational models for human visual perception. It will therefore provide an introduction into the human visual system building on the course on cognitive neuroscience for AI developers. You will learn how the human eye and brain process visual input and what we currently know about the ventral visual stream. We will look at computational models for all different levels of visual processing and discuss how well they measure behavioral data. This lecture is designed to be at the intersection of Computer Science (Computer Vision and Graphics) and Cognitive Neuroscience. After an initial introductory phase, you will in small teams (1-3 students) perform a project to build prototypes for computational models for visual processing, reproduce recent scientific results or experiment with existing models. In addition to the project phase we will read and discuss recent research papers studying potential computational models and investigate how we can evaluate computational models. Please sign up via studon	
6	Learning objectives and skills	By the end of this course, students will be able to • Describe the basic processing steps of visual input in the human brain • Build a computational model for a known processing step • Read recent papers in the discipline and design a follow-up experiment • Choose/design and conduct a small research project • Choose adequate methods to evaluate a computational model • Work in and manage projects	
7	Prerequisites	None	
8	Integration in curriculum	semester: 4	
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242	

		Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Tutorial achievement Written (60 minutes) There are 3 exercises, and participants must pass 2 of them. There is no separate grade for the exercises (only pass/fail).
11	Grading procedure	Tutorial achievement (pass/fail) Written (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 90 h Independent study: 135 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 44400	Radar Signal Processing Radar signal processing	5 ECTS
2	Courses / lectures	Vorlesung: Radar Signal Processing (2 SWS) Übung: Radar Signal Processing Exercises (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Gerhard Krieger	

4	Module coordinator	Prof. Dr.-Ing. Gerhard Krieger
5	Contents	Radar is a key technology for a growing number of sensing tasks that range from the detection, location and tracking of moving objects to high-resolution imaging of surfaces, sub-surfaces and 3-D volumes. While the traditional radar applications focused on aerospace security, weather services and traffic surveillance, radar is now becoming a central contactless sensor technology for the automotive sector, medical diagnostics, gesture control, civil engineering, as well as large scale environmental and climate change monitoring, to name only a few. Associated with the new applications is an increasing demand for advanced signal processing techniques to extract the relevant information from the microwave echoes acquired by single- and multi-aperture radar systems in complex environments. This lecture will give an overview of a variety of one-, two-, and three-dimensional radar signal and image processing algorithms and their application for different sensing tasks. The theoretical derivations are complemented by computer examples and simulations that form an integral part of both the lecture and the exercises. The lecture covers the following topics: • Introduction (radar principles & applications, signal & noise models, interference, Doppler shift) • Basics of Signal Processing with Python (Jupyter Notebooks) • Data Acquisition (I/Q demodulation, complex signal representation, sampling, quantization) • Range Processing (radar waveforms, pulse compression, ambiguity function, sidelobe reduction) • Doppler Processing (MTI, clutter suppression, range-Doppler ambiguities, spectral estimation) • Detection Theory (target models, Neyman-Pearson criterion, CFAR detector, CRBs) • Multi-Channel Processing (spatial filtering, interference suppression, adaptive beamforming) • Synthetic Aperture Radar (basics of coherent imaging, SAR data model, time-domain processing) • SAR Focusing Algorithms (range-Doppler, chirp scaling, motion compensation, autofocus) • SAR Image Analysis (image statistics, speckle filtering, segmentation, classification) • Radar Polarimetry (wave representations, scattering models, polarimetric decomposition) • Interferometry (interferometric processing chain, statistical performance models, applications)

		• Tomography (principles of 3-D imaging, tomographic processing, remote sensing applications) • Space-Time Adaptive Processing (GMTI, optimum processor, pre- & post-Doppler STAP) • Advanced Topics (bi- & multistatic radar, MIMO radar, compressive sensing)
6	Learning objectives and skills	Fachkompetenz Verstehen • understand the basic principles and applications of radar systems • understand the statistical properties of SAR images and their combinations • understand current developments associated with bi- and multistatic SAR, MIMO radar, etc. Anwenden • implement signal processing algorithms for radar detection and parameter estimation • use performance metrics for the evaluation of radar systems and signal processing algorithms • focus coherent radar raw data into high-resolution SAR images • apply space-time adaptive processing techniques for ground moving target indication Analysieren • select and apply spectral processing techniques for clutter and interference suppression • simulate the performance of radar systems in complex environments Erschaffen • combine multiple complex-valued SAR images into higher-level information products
7	Prerequisites	Keine formalen Voraussetzungen, aber grundlegende Kenntnisse erforderlich in • Signal- und Systemtheorie, • Wahrscheinlichkeitstheorie • Lineare Algebra. Von Vorteil wären zudem Vorkenntnisse auf einem Teil der folgenden Gebiete: • statistische Signalverarbeitung • Hochfrequenztechnik • Radarsysteme • Nachrichtentechnische Systeme.
8	Integration in curriculum	semester: 1
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral

		Prüfungsform: mündlich (30 Minuten)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• The handouts distributed at the beginning of each lecture cover the entire material and are fully sufficient for exam preparation. • ◦ M. Richards, Fundamentals of Radar Signal Processing, McGraw-Hill, 2nd ed., 2014 ◦ I. Cumming, F. Wong, Digital Processing of Synthetic Aperture Radar Data, Artech House, 2004 ◦ J. Curlander, R. Donough, Synthetic Aperture Radar Systems & Signal Processing, Wiley, 1991 ◦ F. Ulaby, D. Long, Microwave Radar and Radiometric Remote Sensing, Michigan Press, 2014 ◦ C. Oliver, S. Quegan, Understanding Synthetic Aperture Images, Scitech, 2004 ◦ H. Van Trees, Optimum Array Processing, Wiley Interscience, 2002 ◦ J. Guerci, Space-Time Adaptive Processing for Radar, Artech House, 2nd ed., 2015 ◦ R. Hanssen, Radar Interferometry, Kluwer Academic Publishers, 2001 ◦ J. Li, P. Stoica, MIMO Radar Signal Processing, Wiley, 2008

1	Module name 621649	Advanced Optical Communication Systems Advanced optical communication systems	5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Prof. Dr.-Ing. Bernhard Schmauß
5	Contents	Multiplex Techniques: electrical / optical time division multiplexing, wavelength division multiplexing • Dispersion Management: dispersion and bitrate, dispersion compensation, dispersion in WDM systems • Noise and Power Management: power budget, OSNR management, OSNR calculation • Management of Nonlinearities: self & cross phase modulation (SPM / XPM), four wave mixing (FWM), Raman scattering, solitons • Spectral Efficiency: definition, increase of spectral efficiency • Modulation Formats: intensity modulation, multilevel transmission, CS-RZ, SSB Transmission, DPSK, DQPSK, Coherent Transmission • Optical Regeneration: 2R-Regeneration by nonlinearities, distributed regeneration, 3R-Regeneration
6	Learning objectives and skills	Students • gain detailed Knowledge on concepts and structure of various optical transmission systems. • are able to analyze, to compare and evaluate the quality of optical data signals with respect to different system concepts. • are able to develop and to optimize link designs of optical transmission systems. • are able to systematically improve the performance of optical links taking into account state of the art and leading edge scientific results.
7	Prerequisites	Recommended Prerequisites: • Fundamentals in signals and systems. • Basic knowledge of fiber optics and optoelectronic components recommended.
8	Integration in curriculum	semester: 1
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes) Examination: oral exam (30 Minutes)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h

		Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Agrawal, G.P.: Fiber-Optic Communication Systems, John Wiley & Sons, 1997 Agrawal, G.P.: Nonlinear Fiber Optics, John Wiley & Sons, 3. Auflage, 2001. Kaminow, I, Koch, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002. Kaminow, I, Li, T., Willner, A.: Optical Fiber Telecommunications VA, Academic Press, 2008. Lecture notes.

1	Module name 67145	Waveguides, optical fibres and photonic crystal fibres	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Waveguides, optical fibres and photonic crystal fibres (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Nicolas Joly Prof. Dr.-Ing. Bernhard Schmauß	

4	Module coordinator	Prof. Dr. Nicolas Joly Prof. Dr.-Ing. Bernhard Schmauß
5	Contents	1) Fundamental of waveguides (Guidance mechanism, modes and dispersion, geometrical and electromagnetic approach) 2) Photonic crystal fibres (PCF) 3) Nonlinear optics in PCF (soliton, supercontinuum generation, nonlinear optics in gases in hollow-core PCF) 4) Optical communication systems (system outline, waveguide components, transmission effects, performance limitations) 5) Optical fibre sensors: fibre sensing principles, waveguide-based sensing component, distributed sensing, sensor, network, sensor signal processing)
6	Learning objectives and skills	The students will be able - to identify a particular type of microstructure fibre for a dedicated experiment - to calculate the mode content supported by a specific fibre and model the modal properties - to evaluate the potential limitations of an optical fibre due to nonlinear effects - to choose the appropriate fibre (dispersion and nonlinearity) to generate quiet or very broad supercontinuum spectral using a photonic crystal fibre - to choose the appropriate type of fibre-based sensor according to the signal to probe - to understand the performance limitation of the telecommunications systems
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester

15	Teaching and examination language	english
16	Bibliography	

1	Module name 92519	Robotics 1	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Knut Graichen Dr.-Ing. Andreas Völz
5	Contents	This lecture introduces the fundamentals of robotics with a focus on manipulator control. The course covers the following topics: - Modeling: coordinate systems and transformations, parameterization of rotation matrices, forward and inverse kinematics, Jacobians and singularities - Trajectory planning: polynomial and trapezoidal trajectories, trajectories with intermediate points, trajectories in task space - Linear control: actuator dynamics, decentralized motion control, basics of task space and force control
6	Learning objectives and skills	After successful completion of the module, students will be able to - mathematically describe and analyze the kinematics of robotic manipulators. - plan trajectories for robot motions. - design and implement linear methods for robot motion and force control.
7	Prerequisites	- Basis knowledge of advanced mathematics - Basic knowledge of control theory
8	Integration in curriculum	semester: 6
9	Module compatibility	Planning & Control - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	M. Spong, S. Hutchinson und M. Vidyasagar: Robot Modeling and Control. Wiley, 2005. B. Siciliano, L. Sciavicco, G. Oriolo und L. Villani: Robotics Modelling, Planning and Control. Springer, 2009. J. Craig: Introduction to Robotics: Mechanics and Control. Pearson, 2018.

1	Module name 92529	Nonlinear Control Systems Nonlinear control systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Knut Graichen
5	Contents	Many control problems are nonlinear by nature. Classical control methods are based on linear approximations or a linearization of these systems in the neighborhood of setpoints to be controlled. In contrast to linear control theory, this module focuses on advanced nonlinear methods for the analysis and control of nonlinear systems by exploiting structural properties. In summary, the course covers the following topics: • Examples of nonlinear physical systems and nonlinear phenomena • Introduction to computer algebra software • Analysis of nonlinear systems • Stability of nonlinear systems (Lyapunov stability) • Lyapunov-based control design (Backstepping) • Reachability/controllability and observability of nonlinear systems • Exact linearization via feedback • Differential flatness of nonlinear systems • Flatness-based feedforward and feedback control of nonlinear systems
6	Learning objectives and skills	After successful completion of the module, students will be able to • describe and analyze nonlinear systems • determine the input/output behavior of nonlinear systems • design nonlinear state feedback controllers via exact input-output and input-state linearization • apply the concept of differential flatness for the feedforward feedback control of nonlinear systems • use computer algebra software for the analysis and control design of nonlinear systems
7	Prerequisites	Basic knowledge of advanced mathematics Linear control theory (state space methods), e.g. "Regelungstechnik B"
8	Integration in curriculum	semester: 6
9	Module compatibility	Planning & Control - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h

		Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• H.K. Khalil. Nonlinear Systems, Prentice Hall, 2002 • S. Sastry. Nonlinear Systems, Springer, 1999 • A. Isidori. Nonlinear Control Systems, Springer, 3. Auflage, 1995 • J. Adamy. Nichtlineare Regelungen, Springer, 2009 • J.-J. Slotine, W. Li. Applied Nonlinear Control, Prentice Hall, 1991 • M. Vidyasagar. Nonlinear Systems Analysis, Prentice Hall, 2. Auflage, 1993 • M. Krstic, I. Kanellakopoulos, P. Kokotovic. Nonlinear and Adaptive Control Design, John Wiley & Sons, 1995

1	Module name 92528	Numerical Optimization and Model Predictive Control Numerical optimization and model predictive control	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Knut Graichen
5	Contents	Many problems in economy and industry require an optimal solution under consideration of specific criteria and constraints. From a mathematical point of view, this requires the numerical solution of a parametric optimization problem or a dynamic optimization problem. The latter formulation accounts for the dynamics of the underlying process and is particularly relevant in the context of optimal control and model predictive control (MPC). In summary, the course covers the following topics: • Introduction to and examples of static and dynamic optimization problems • Unconstrained numerical optimization (optimality conditions, numerical methods) • Constrained numerical optimization (linear/quadratic/nonlinear problems, optimality conditions, numerical methods) • Dynamical optimization / optimal control problems (calculus of variations, optimality conditions, PMP, numerical methods) • Nonlinear model predictive control (formulations, stability, real-time solution)
6	Learning objectives and skills	After successful completion of the module, students will be able to • differentiate the problem classes of parametric and dynamic optimization • formulate and analyze practical optimization problems • derive and solve the optimality conditions for unconstrained and constrained optimization problems using state-of-the-art software tools • classify the different formulations and stability criteria for nonlinear model predictive control • design a model predictive controller for a given control task and analyze the performance and stability properties in closed loop • realize and implement a real-time MPC for highly dynamical nonlinear systems with sampling times in the (sub)millisecond range using modern state-of-the-art (N)MPC software
7	Prerequisites	Basic knowledge of advanced mathematics (especially linear algebra) Basic knowledge of dynamical systems in time domain description (e.g. Regelungstechnik B)
8	Integration in curriculum	semester: 6

9	Module compatibility	Planning & Control - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	S. Boyd, L. Vandenberghe. Convex Optimization. Cambridge University Press, 2004 J. Nocedal, S.J. Wright. Numerical Optimization. New York: Springer, 2006 M. Papageorgiou, M. Leibold, M. Buss. Optimierung. Berlin: Springer, 2012 C.T. Kelley. Iterative Methods for Optimization. Society for Industrial und Applied Mathematics (SIAM), 1999 D.P. Bertsekas. Nonlinear Programming. Belmont. Athena Scientific, 1999 E. Camacho, C. Alba. Model Predictive Control. 2. Auflage, Springer, 2004 L. Grüne, J. Pannek. Nonlinear Model Predictive Control: Theory and Algorithms, Springer, 2011

1	Module name 43405	Introduction to Deep Learning Introduction to deep learning	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Introduction to Deep Learning (2 SWS) Übung: Supplements for Introduction to Deep Learning (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Vasileios Belagiannis Marc Hölle	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis
5	Contents	The students will learn the basics in deep learning, including classical neural network models and recent architectures. The students will acquire knowledge on processing different types of data with deep neural networks. In the exercises, the students will implement some of the standard models for classification or regression tasks and acquire knowledge on machine learning applications. The lecture topics include: • Learning from data, machine learning and deep learning • Machine learning principles • Artificial neural networks • Convolutional neural networks • Back-propagation • Network optimization • Initialisation, regularisation • Deep network architectures • Generative models • Auto-encoders • Sequential models • Deep learning applications
6	Learning objectives and skills	The students will learn: • Machine learning theory • Artificial neural networks • Deep neural networks • Modern architectures • Model and parameter learning
7	Prerequisites	Basic knowledge of higher mathematics and programming
8	Integration in curriculum	semester: 5;6

9	Module compatibility	Planning & Control - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242	
10	Method of examination	Written examination (90 minutes) Schriftliche Prüfung von 90min Dauer	
11	Grading procedure	Written examination (100%)	
12	Module frequency	Only in winter semester	
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h	
14	Module duration	1 semester	
15	Teaching and examination language	english	
16	Bibliography		• Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning. • Rojas, R. (2013). Neural networks: a systematic introduction. • Friedman, J., Hastie, T., & Tibshirani, R. (2001). The elements of statistical learning.

1	Module name 97060	Regelungstechnik B (Zustandsraummethoden) Control engineering B (State-space methods)	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Regelungstechnik B (Zustandsraummethoden) (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr.-Ing. Knut Graichen	

4	Module coordinator	Prof. Dr.-Ing. Knut Graichen
5	Contents	Das Modul vermittelt die Grundlagen zur Beschreibung und Untersuchung von linearen dynamischen Systemen mit mehreren Ein- und Ausgangsgrößen im Zustandsraum sowie den zustandsraumbasierten Regler- und Beobachterentwurf. Die Inhalte sind: • Motivation der Zustandsraumbetrachtung dynamischer Systeme in der Regelungstechnik • Zustandsraumdarstellung dynamischer Systeme und deren Vereinfachung durch Linearisierung • Analyse linearer und zeitinvarianter Systeme: Stabilität, Steuerbarkeit, Beobachtbarkeit, Zusammenhang mit Ein-/Ausgangsbetrachtung • Auslegung von linearen Zustandsreglern für lineare Eingrößensysteme • Erweiterte Regelkreisstrukturen, insbesondere Vorsteuerung und Störgrößenkompensation • Entwurf von Zustands- und Störgrößenbeobachtern und Kombination mit Zustandsreglern (Separationsprinzip)
6	Learning objectives and skills	Die Studierenden können • die Vorzüge der Zustandsraumbetrachtung im Vergleich zur Ein-/Ausgangsbetrachtung darlegen. • für dynamische Systeme die Zustandsgleichungen aufstellen und durch Linearisierung vereinfachen. • für LZI-Systeme die Zustandsgleichungen in Normalformen transformieren. • Stabilität, Steuer- und Beobachtbarkeit von Zustandssystemen definieren und LZI-Systeme daraufhin untersuchen. • ausführen, wie diese Eigenschaften mit den Eigenwerten und Nullstellen von LZI-Zustandssystemen zusammenhängen. • den Aufbau einer Zwei-Freiheitsgrade-Zustandsregelung angeben und die Zweckbestimmung ihrer einzelnen Komponenten erläutern. • realisierbare Vorsteuerungen zur Einstellung des Sollverhaltens entwerfen. • Zielstellung und Aufbau eines Zustandsbeobachters erläutern. • diesen zu einem Störbeobachter erweitern und Störaufschaltungen zur Kompensation von Dauerstörungen konzipieren. • beobachterbasierte Zustandsregelungen durch Eigenwertvorgabe entwerfen.

		die Vorlesungsinhalte auf verwandte Problemstellungen übertragen und sich die Zustandsraummethoden der Regelungstechnik selbständig weiter erschließen.
7	Prerequisites	Empfohlene Vorkenntnisse: Vektor- und Matrizenrechnung sowie Grundlagen der Regelungstechnik (klassische Frequenzbereichsmethoden; kann auch parallel gehört werden, siehe Regelungstechnik A)
8	Integration in curriculum	semester: 1
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Die Summe der in den freiwilligen Testaten erzielten Punktzahl wird zu max. 10% auf die Klausurpunktzahl angerechnet. Hiermit ist eine Verbesserung der Klausurbewertung um bis zu 0,7 Notenpunkte möglich. Die Anrechnung erfolgt nur, wenn Sie die Prüfung an sich mit der Mindestnote 4,0 bestanden haben. Der Bonus kann nur einmal im Prüfungszeitraum der Vorlesung angerechnet werden, entweder zum Haupttermin nach Vorlesungsende oder zum Nachholtermin im Folgesemester, wenn der Haupttermin nicht wahrgenommen wurde.
11	Grading procedure	Written examination (100%) Die Summe der in den freiwilligen Testaten erzielten Punktzahl wird zu max. 10% auf die Klausurpunktzahl angerechnet. Hiermit ist eine Verbesserung der Klausurbewertung um bis zu 0,7 Notenpunkte möglich. Die Anrechnung erfolgt nur, wenn Sie die Prüfung an sich mit der Mindestnote 4,0 bestanden haben. Der Bonus kann nur einmal im Prüfungszeitraum der Vorlesung angerechnet werden, entweder zum Haupttermin nach Vorlesungsende oder zum Nachholtermin im Folgesemester, wenn der Haupttermin nicht wahrgenommen wurde.
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	- C.T. Chen. Control System Design, Pond Woods Press, 1987 O. Föllinger. Regelungstechnik: Einführung in die Methoden und ihre Anwendung. 8. Auflage, Hüthig, 1994 H. Geering. Regelungstechnik, 6. Auflage, Springer, 2004 T. Kailath. Linear Systems, Prentice Hall, 1980 G. Ludyk. Theoretische Regelungstechnik 1, Springer, 1995 - D.G. Luenberger. Introduction to Dynamic Systems, John Wiley & Sons, 1979 J. Lunze. Regelungstechnik 1, 12. Auflage, Springer, 2020 J. Lunze. Regelungstechnik 2, 10. Auflage, Springer, 2020

	• L. Padulo, M.A. Arbib. System Theory, W.B. Saunders Company, 1974 • W.J. Rugh. Linear System Theory 2, Prentice Hall, 1996

1	Module name 92535	Robotics 2	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Robotics 2 (4 SWS)	5 ECTS
3	Lecturers	Dr.-Ing. Andreas Völz	

4	Module coordinator	Dr.-Ing. Andreas Völz
5	Contents	This lecture introduces advanced methods of robotics with a focus on manipulator control. The course covers the following topics: • Dynamics: Euler-Lagrange formulation, recursive Newton-Euler algorithm, extensions of the dynamical model • Nonlinear control: Lyapunov stability, gravity compensation, inverse dynamics, adaptive control, task space control • Motion planning: Time-optimal trajectory generation, collision checking, configuration space, local path planning, global path planning • Mobile robots: Basics of control and planning
6	Learning objectives and skills	The students are able to • derive the dynamical model of a robotic manipulator using the Euler-Lagrange equations and the recursive Newton-Euler algorithm • design and implement nonlinear methods for robot motion and force control and analyze their stability using Lyapunov theory • plan collision-free motions for robots in known environments using local and global planning algorithms
7	Prerequisites	Recommended prior knowledge: Basics of advanced mathematics, control theory and robotics
8	Integration in curriculum	semester: 6
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• M. Spong, S. Hutchinson und M. Vidyasagar: Robot Modeling and Control. Wiley, 2005. • B. Siciliano, L. Sciavicco, G. Oriolo und L. Villani: Robotics Modelling, Planning and Control. Springer, 2009. • J. Craig: Introduction to Robotics: Mechanics and Control. Pearson, 2018.

	• S. LaValle: Planning algorithms, Cambridge University Press, 2006.

1	Module name 97360	Digitale Regelung Digital control	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr.-Ing. Andreas Michalka
5	Contents	Es werden Aufbau u. mathematische Beschreibung digitaler Regelkreise für LZI-Systeme sowie Verfahren zu deren Analyse und Synthese betrachtet: • quasikontinuierliche Beschreibung und Regelung der Strecke unter Berücksichtigung der DA- bzw. AD-Umsetzer • zeitdiskrete Beschreibung der Regelstrecke als Zustandsgleichung oder z-Übertragungsfunktion • Analyse von Abtastsystemen, Stabilität, Steuer- und Beobachtbarkeit • Regelungssynthese: Steuerungsentwurf, Zustandsregelung und Beobachterentwurf, Störungen im Regelkreis, Berücksichtigung von Totzeiten, Intersampling-Verhalten".
6	Learning objectives and skills	Die Studierenden • erläutern Aufbau und Bedeutung digitaler Regelkreise. • leiten mathematische Beschreibungen des Abtastsystems in Form von Zustandsgleichungen oder z-Übertragungsfunktionen her. • analysieren Abtastsysteme und konzipieren digitale Regelungssysteme auf Basis quasikontinuierlicher sowie zeitdiskreter Vorgehensweisen. • entwerfen Steuerungen, Regelungen und Beobachter und bewerten die erzielten Ergebnisse. • diskutieren abtastregelungsspezifische Effekte und bewerten Ergebnisse im Vergleich mit dem kontinuierlichen Systemverhalten.
7	Prerequisites	Es wird empfohlen folgende Module zu absolvieren, bevor dieses Modul belegt wird: • Regelungstechnik A (Grundlagen) (RT A) oder Einführung in die Regelungstechnik (ERT) • Regelungstechnik B (Zustandsraummethoden) (RT B)
8	Integration in curriculum	semester: 1
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Schriftliche Prüfung (Klausur, mit 90 Minuten Dauer).
11	Grading procedure	Written examination (100%)

12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 94961	Schätzverfahren in der Regelungstechnik Estimation Methods for Control Systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Thomas Moor
5	Contents	• Überbestimmte lineare Gleichungssysteme zur Parameter- und Zustandsschätzung • Least Squares Schätzer via quadratischer Ergänzung • Least Squares Schätzer via Projektionssatz • Linear Least Mean Squares Schätzer stochastischer Größen • Kalman-Filter • Extended Kalman-Filter
6	Learning objectives and skills	Die Studierenden • erkennen, ob und wie eine regelungstechnische Problemstellung in dem vorgestellten Rahmen der Schätzverfahren formuliert und gelöst werden kann • erläutern die herangezogenen mathematischen Grundlagen, insbesondere aus der linearen Algebra • können die vermittelten Ansätze im Kontext von einfachen Beispielen anwenden und die jeweils erzielten Ergebnisse kritisch bewerten.
7	Prerequisites	Grundlagen der Analysis und Algebra, wie sie z.B. in den Veranstaltungen "Mathematik für Ingenieure" angeboten werden; Grundlagen der Regelungstechnik, z.B. durch Belegung der Module: • Regelungstechnik A (Grundlagen) • Regelungstechnik B (Zustandsraummethoden)
8	Integration in curriculum	semester: 5
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	Kailath et al.; Linear Estimation, Prentice Hall, 2000.

1	Module name 92430	Ereignisdiskrete Systeme	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Thomas Moor
5	Contents	Formale Sprachen als Modelle ereignisdiskreter Dynamik • reguläre Ausdrücke, endliche Automaten, Nerode-Äquivalenz • natürliche Projektion, synchrone Komposition, Konfliktfreiheit. Entwurf ereignisdiskreter Regler: • Sicherheitsspezifikation, Konfliktfreiheit • supremale steuerbare Teilsprache, Fixpunktiterationen • Normalität, Regelung unter eingeschränkter Beobachtbarkeit. Anwendungsstudie: • Modellbildung eines einfachen technischen Prozesses • Spezifikation/Entwurf/Simulation am Anwendungsbeispiel
6	Learning objectives and skills	Teilnehmer dieser Veranstaltung • erklären, illustrieren und validieren die vorgestellten Grundlagen formaler Sprachen, • entwickeln einfache Ergänzungen zu den vorgestellten Grundlagen formaler Sprachen, • erklären und illustrieren die vorgestellten Entwurfsverfahren, • überprüfen die vorgestellten Entwurfsverfahren hinsichtlich einzelner Lösungseigenschaften, • entwickeln ereignisdiskrete Modelle einfacher technischer Prozesse, einschließlich formaler Spezifikationen, • wählen im Kontext einfacher technischer Prozesse geeignete Entwurfsverfahren aus und wenden diese kritisch an, • bewerten ihre Regelkreise im Simulationsexperiment.
7	Prerequisites	Es wird empfohlen, eines der folgenden Module zu absolvieren, bevor dieses Modul belegt wird: • Regelungstechnik A (Grundlagen) (RT A) • Einführung in die Regelungstechnik (ERT)
8	Integration in curriculum	semester: 1
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Schriftliche Prüfung (Klausur, mit 90 Minuten Dauer).
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h

14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	Cassandras, C.G., Lafortune, S.: Introduction to Discrete Event Systems, Kluwer, 1999

1	Module name 96430	Statistical Signal Processing Statistical signal processing	5 ECTS
2	Courses / lectures	Übung: Übung zur Statistischen Signalverarbeitung (1 SWS) Vorlesung: Statistische Signalverarbeitung (3 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr.-Ing. Sebastian Schlecht Baoqi Bai	

4	Module coordinator	Prof. Dr.-Ing. Sebastian Schlecht
5	Contents	The course concentrates on fundamental methods of statistical signal processing and their applications. The main topics are: - Discrete-time stochastic processes in the time and frequency domain: Random variables (RVs), probability distributions and densities, expectations of random variables, transformation of RVs, vectors of normally distributed RVs, time-discrete random processes: probability distribution and densities, expectation, stationarity, cyclostationarity, ergodicity, correlation functions and correlation matrices, spectral representations, principal component analysis (PCA), Karhunen-Loève transform (KLT). - Estimation theory: estimation criteria, prediction, classical and Bayesian parameter estimation (including MMSE, Maximum Likelihood, and Maximum A Posteriori estimation), Cramer-Rao bound - Linear signal models: Parametric models (cepstral decomposition, Paley-Wiener theorem, spectral flatness), non-parametric models (all-pole, all-zero and pole-zero models, lattice structures, Yule-Walker equations, PARCOR coefficients, cepstral representation) - Signal estimation: Supervised estimation, problem classes, orthogonality principle, MMSE estimation, linear MMSE estimation for normally distributed random processes, optimum FIR filtering, optimum linear filtering for stationary processes, prediction and smoothing, Kalman filters, optimum multichannel filtering (Wiener filter, LCMV, MVDR, GSC) - Adaptive filtering: Gradient methods, LMS, NLMS, APA and RLS algorithms and their convergence behavior
6	Learning objectives and skills	The students: - analyze the statistical properties of random variables, random vectors, and stochastic processes by probability density functions and expectations as well as correlation functions and matrices and their frequency-domain representations - know the Gaussian distribution and its role to describe the properties of random variables, vectors and processes - understand the differences between classical and Bayesian estimation, derive and analyze MMSE and ML estimators for specific estimation problems, especially for signal estimation

		- analyze and evaluate optimum linear MMSE estimators (single- and multichannel Wiener filter and Kalman filter) for direct and inverse supervised estimation problems - evaluate adaptive filters for the identification of optimum linear estimators.
7	Prerequisites	Courses on signals and systems as well as digital signal processing strongly recommended
8	Integration in curriculum	semester: 5
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Sensing & Perception - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Schriftliche Klausur von 90min Dauer.
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	A. Papoulis, S. Pillai: Probability, Random Variables and Stochastic Processes; McGraw-Hill, 2002 D. Manolakis, V. Ingle, S. Kogon: Statistical and Adaptive Signal Processing; Artech House, 2005

1	Module name 48440	Machine Learning in Signal Processing Machine learning in signal processing	5 ECTS
2	Courses / lectures	Übung: Übung zu Maschinelles Lernen in der Signalverarbeitung (2 SWS) Vorlesung: Maschinelles Lernen in der Signalverarbeitung (2 SWS)	- 5 ECTS
3	Lecturers	Michele De Vita Marc Hölle Prof. Dr. Vasileios Belagiannis	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis
5	Contents	This course is an introduction into machine learning and artificial intelligence. The special emphasis is on applications to modern signal processing problems. The course is focused on design principles of machine learning algorithms. The lectures start with a short introduction, where the nomenclature is defined. After this, probabilistic graphical models are introduced and the use of latent variables is discussed, concluding with a discussion of hidden Markov models and Markov fields. The second part of the course is about deep learning and covers the use of deep neural networks for machine learning tasks. In the last part of the lecture, the use of deep neural networks for speech processing tasks is introduced. The course is based on the materials and video footage from Dr. Roland Maas. He is an outstanding machine learning expert and a former member of the Chair of Multimedia Communications and Signal Processing.
6	Learning objectives and skills	After attending the lecture, students will be able to • understand regression and classification problems • apply PDF estimation algorithms • understand Gaussian mixture models and expectation-maximization • apply principal component analysis and independent component analysis • assess different estimation algorithms • explain the application of machine learning to system identification • apply hidden Markov models • understand different artificial neural network architectures • explain deep learning principles • apply artificial neural networks • devise learning strategies for deep neural networks • assess the application of deep neural networks for speech processing tasks.
7	Prerequisites	None
8	Integration in curriculum	semester: 5
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242

		Sensing & Perception - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Schriftliche Prüfung von 90min Dauer
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Literature: • C. M. Bishop: Pattern Recognition and Machine Learning, http://www.research.microsoft.com/en-us/um/people/cmbishop/PRML • S. Theodoridis and K. Koutroumbas: Pattern Recognition • M. Nielsen: Neural Networks and Deep Learning.

1	Module name 44120	Pattern Analysis Pattern analysis	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	PD Dr.-Ing. Christian Riess
5	Contents	This lecture is the sequel to the lecture "<i>Pattern Recognition</i>". As such, it covers topics from the chapters 8-14 from the book "<i>Pattern Recognition and Machine Learning</i>" by Christopher Bishop. These topics include various aspects of Bayesian modeling, including (but not limited to) • probabilistic graphical models • mixture modeling • variational inference • sampling methods • manifold learning • Markov random fields • hidden Markov models • tree-based methods • ensembling
6	Learning objectives and skills	The students • explain the discussed methods for classification, prediction, and analysis of patterns, • compare and analyze methods for manifold learning and select a suited method for a given set of features and a given problem, • compare and analyze methods for probability density estimation and select a suited method for a given set of features and a given problem, • apply non-parametric probability density estimation to pattern analysis problems, • apply dimensionality reduction techniques to high-dimensional feature spaces, • explain statistic modeling of feature sets and sequences of features, • explain statistic modeling of statistical dependencies
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable (60 minutes) Die Prüfung ist eine schriftliche Klausur mit Multiple Choice mit einer Dauer von 60 Minuten.

		--- The form of examination is a written exam with multiple choice with a duration of 60 minutes.
11	Grading procedure	Variable (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Begleitende Literatur / Accompanying literature: • C. Bishop: Pattern Recognition and Machine Learning, Springer Verlag, Heidelberg, 2006 • T. Hastie, R. Tibshirani und J. Friedman: The Elements of Statistical Learning, 2nd Edition, Springer Verlag, 2009 • A. Criminisi and J. Shotton: Decision Forests for Computer Vision and Medical Image Analysis, Springer, 2013

1	Module name 44130	Pattern Recognition Pattern recognition	5 ECTS
2	Courses / lectures	Übung: PR Exercise (1 SWS) Vorlesung: Pattern Recognition (3 SWS)	1,25 ECTS 3,75 ECTS
3	Lecturers	Linda-Sophie Schneider Dr.-Ing. Siming Bayer Prof. Dr.-Ing. Andreas Maier	

4	Module coordinator	Prof. Dr.-Ing. Andreas Maier
5	Contents	Mathematical foundations of machine learning based on the following classification methods: • Bayesian classifier • Logistic Regression • Naive Bayes classifier • Discriminant Analysis • norms and norm dependent linear regression • Rosenblatt's Perceptron • unconstraint and constraint optimization • Support Vector Machines (SVM) • kernel methods • Expectation Maximization (EM) Algorithm and Gaussian Mixture Models (GMMs) • Independent Component Analysis (ICA) • Model Assessment • AdaBoost Mathematische Grundlagen der maschinellen Klassifikation am Beispiel folgender Klassifikatoren: • Bayes-Klassifikator • Logistische Regression • Naiver Bayes-Klassifikator • Diskriminanzanalyse • Normen und normabhängige Regression • Rosenblatts Perzeptron • Optimierung ohne und mit Nebenbedingungen • Support Vector Maschines (SVM) • Kernelmethoden • Expectation Maximization (EM)-Algorithmus und Gaußsche Mischverteilungen (GMMs) • Analyse durch unabhängige Komponenten • Modellbewertung • AdaBoost
6	Learning objectives and skills	Die Studierenden • verstehen die Struktur von Systemen zur maschinellen Klassifikation einfacher Muster • erläutern die mathematischen Grundlagen ausgewählter maschineller Klassifikatoren • wenden Klassifikatoren zur Lösung konkreter Klassifikationsproblem an

		• beurteilen unterschiedliche Klassifikatoren in Bezug auf ihre Eignung • verstehen in der Programmiersprache Python geschriebene Lösungen von Klassifikationsproblemen und Implementierungen von Klassifikatoren Students • understand the structure of machine learning systems for simple patterns • explain the mathematical foundations of selected machine learning techniques • apply classification techniques in order to solve given classification tasks • evaluate various classifiers with respect to their suitability to solve the given problem • understand solutions of classification problems and implementations of classifiers written in the programming language Python
7	Prerequisites	• Well grounded in probability calculus, linear algebra/matrix calculus • The attendance of our bachelor course 'Introduction to Pattern Recognition' is not required but certainly helpful. • Gute Kenntnisse in Wahrscheinlichkeitsrechnung und Linearer Algebra/Matrizenrechnung • Der Besuch der Bachelor-Vorlesung 'Introduction to Pattern Recognition' ist zwar keine Voraussetzung, aber sicherlich von Vorteil.
8	Integration in curriculum	semester: 1
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german or english english
16	Bibliography	• Richard O. Duda, Peter E. Hart, David G. Stock: Pattern Classification, 2nd edition, John Wiley&Sons, New York, 2001 • Trevor Hastie, Robert Tibshirani, Jerome Friedman: The Elements of Statistical Learning - Data Mining, Inference, and Prediction, 2nd edition, Springer, New York, 2009 • Christopher M. Bishop: Pattern Recognition and Machine Learning, Springer, New York, 2006

1	Module name 93185	Reinforcement Learning Reinforcement learning	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr.-Ing. Christopher Mutschler	
5	Contents	The lecture aims at teachin Reinforcement Learning (RL) and will cover the following topics: • Introduction to Reinforcement Learning (Agent-Environment-Interface, Markov Decision Processes) • Dynamic Programming (Bellman Equations, Value Iteration, Policy Iteration) • Model-Free Prediction • Model-Free Control • Value Function Approximation (Linear VFA and DQNs) • Policy-based Reinforcement Learning (Monte-Carlo Policy Gradient, Advantage Estimators, TRPO, PPO) • Model-based RL • Offline RL • Explainable RL • Exploration-Exploitation • Simulation to Reality Transfer • Research frontiers & hot topics, Sim2Real & Real-World Applications	
6	Learning objectives and skills	The students will learn to • understand the basic principle behind sequestration decision making problems and how to translate them into a formal model • compare and analyze methods different agents to search for policies • implement the presented methods in PyTorch, • discuss the social impact of applications that automate decision making	
7	Prerequisites	Es handelt sich hier um eine Spezialisierungsvorlesung, eine erfolgreiche Absolvierung der Vorlesungen IntroPR" und/oder Pattern Recognition"/"Pattern Analysis" wird empfohlen. Konzepte, die in IntroPR" vermittelt werden, werden hier als Grundwissen vorausgesetzt.	
8	Integration in curriculum	semester: 1	
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242	
10	Method of examination	Variable (90 minutes) • The examination will include a written exam of 90 minutes at the end of the semester	

		The exam will cover the content of the lecture as well as that of the exercises (the exam will hence contain a mixture of theoretical questions and practical coding tasks) Please note that the exam will only take place in summer terms.
11	Grading procedure	Variable (100%) Written Exam (100 %)
12	Module frequency	Only in summer semester The lecture and exam will only be able during summer terms.
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	- Richard S. Sutton and Andrew G. Barto. 2018. Reinforcement Learning: An Introduction. A Bradford Book, Cambridge, MA, USA. - Bellman, R.E. 1957. Dynamic Programming. Princeton University Press, Princeton, NJ. Republished 2003: Dover, ISBN 0-486-42809-5. - Csaba Szepesvari and Ronald Brachman and Thomas Dietterich. 2010. Algorithms for Reinforcement Learning. Morgan and Claypool Publishers. - Warren B. Powell. 2011. Approximate Dynamic Programming. Wiley. - Maxim Lapan. 2020. Deep Reinforcement Learning Hands-On: Apply modern RL methods to practical problems of chatbots, robotics, discrete optimization, web automation, and more, 2nd Edition. Packt Publishing. - Dimitri P. Bertsekas. 2017. Dynamic Programming and Optimal Control. Athena Scientific. - Miguel Morales. 2020. grokking Deep Reinforcement Learning. Manning. - Laura Graesser and Keng Wah Loon. 2019. Foundations of Deep Reinforcement Learning: Theory and Practice in Python. Addison-Wesley Data & Analytics.

1	Module name 94951	Grundlagen der Robotik Fundamentals of robotics	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Jörg Franke
5	Contents	Das Modul Grundlagen der Robotik richtet sich insbesondere an die Studierenden der Informatik, des Maschinenbaus, der Mechatronik, der Medizintechnik sowie des Wirtschaftsingenieurwesens. Es werden zunächst die Grundlagen der modernen Robotik erläutert und anschließend fachspezifische Grundlagen zur Konzeption, Implementierung und Realisierung von Robotersystemen vermittelt. Hierbei liegt der Fokus neben klassischen Industrierobotern auch auf neuen Robotertechnologien für den Service-, Pflege- und Medizinbereich. Es werden weiterhin die Grundlagen des Robot Operating System (ROS) vermittelt und es wird durch praktische Übungen die Arbeit und Roboterprogrammierung mit ROS erlernt. Das Modul umfasst hierfür die nachfolgenden Themenschwerpunkte: • Bauformen, Begriffe, Definitionen, Historie, rechtliche Grundlagen und Roboterethik • Roboteranwendungen in Industrie, Service, Pflege und Medizin • Sensorik und Aktorik für Robotersysteme • Kinematik und Dynamik verschiedener Roboterbauformen • Steuerung, Regelung und Bahnplanung • Varianten der Roboterprogrammierung • Planung und Simulation von Robotersystemen • Robot Operating System (ROS) • Computer Vision (OpenCV)
6	Learning objectives and skills	Ziel ist, den Studierenden einen fundierten Überblick über aktuelle Roboterapplikationen zu vermitteln sowie die grundlegenden Bauformen, Begrifflichkeiten und gesetzlichen Rahmenbedingungen vorzustellen. Darauf aufbauen werden die notwendigen technischen Grundlagen moderner Robotersysteme sowie die Programmierung eines Roboters mit ROS erlernt. Die Studierenden sind in der Lage: • Roboter hinsichtlich ihrer Eigenschaften zu klassifizieren, das für eine vorgegebene Anwendung optimale Robotersystem auszuwählen und hierbei ethische und arbeitsschutzrechtliche Aspekte zu berücksichtigen. • Robotersysteme auszulegen, zu entwickeln und die erforderlichen Bewegungsabläufe zu planen, • die für verschiedene Roboterapplikationen notwendige Sensorik und Aktorik auszuwählen,

		• Robotersysteme durch den Einsatz von Planungs- und Simulationswerkzeugen zu validieren • sowie Roboter mit Hilfe des Robot Operating Systems zu programmieren und zu steuern.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (120 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 92880	Robotics Frameworks Robotics frameworks	5 ECTS
2	Courses / lectures	Übung: Exercise Robotics Frameworks (0 SWS) Vorlesung: Robotics Frameworks (4 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Nina Merz Dr.-Ing. Sebastian Reitelshöfer	

4	Module coordinator	Prof. Dr.-Ing. Jörg Franke
5	Contents	• Basic concepts of robotics • Basic concepts of the Robot Operating System • Simulation of robots in virtual environments • Computer vision and machine learning in the context of robotics • Path and gripping grasp planning • Localization, mapping and navigation of mobile robots • Flow control with state machines for complex robot tasks • Introduction to relevant software frameworks for specific tasks (Robot Operating System, Gazebo, OpenCV, Tensorflow) • Solving a complex practical task as a team
6	Learning objectives and skills	In this module, students independently implement advanced tasks in robotics and related topics such as simulation, computer vision and machine learning using concrete examples. In doing so, the students deal with various established software frameworks and learn how to use them. Students are taught the following technical and methodological competences: After completing the module, students will be able to • Classify important terms of robotics • Understand the challenges of modern robotics in relation to complex tasks and develop approaches to solve them. • Analyse and practically apply complex issues in robotics (robotics frameworks, simulation tools and frameworks for image processing and artificial intelligence) • Explain and apply methods of robot motion control and planning • Explain the self-localisation of mobile robots and examine it using examples The students additionally acquire and train the following personal and social competences within the framework of the team task: After completing the module, the students can • Independently solve preparatory tasks • Organize their working time • Work together with other students in a group in a goal-oriented manner • Assess their own strengths and use them in a targeted way in the team performance

7	Prerequisites	Recommended Prerequisites : Basic knowledge of programming languages C++ and Python, additional information can be found on StudOn
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 95280	Verteilte Systeme Distributed systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	PD Dr.-Ing. Tobias Distler
5	Contents	Verteilte Systeme bestehen aus mehreren Rechnern, die über ein Netzwerk miteinander verbunden sind und einen gemeinsamen Dienst erbringen. Obwohl die beteiligten Rechner hierfür in weiten Teilen unabhängig voneinander agieren, erscheinen sie ihren Nutzern gegenüber in der Gesamtheit dabei trotzdem als ein einheitliches System. Die Einsatzmöglichkeiten für verteilte Systeme erstrecken sich über ein weites Spektrum an Szenarien: Von der Zusammenschaltung kleinster Rechenknoten zur Sammlung von Daten im Rahmen von Sensornetzwerken über Steuerungssysteme für Kraftfahrzeuge und Industrieanlagen bis hin zu weltumspannenden, Internet-gestützten Infrastrukturen mit Komponenten in Datenzentren auf verschiedenen Kontinenten. Ziel dieses Moduls ist es, die sich durch die speziellen Eigenschaften verteilter Systeme ergebenden Problemstellungen zu verdeutlichen und Ansätze zu vermitteln, mit deren Hilfe sie gelöst werden können; Beispiele hierfür sind etwa die Interaktion zwischen heterogenen Systemkomponenten, der Umgang mit erhöhten Netzwerklatenzen sowie die Wahrung konsistenter Zustände über Rechengrenzen hinweg. Gleichzeitig zeigt das Modul auf, dass die Verteiltheit eines Systems nicht nur Herausforderungen mit sich bringt, sondern auf der anderen Seite auch Chancen eröffnet. Dies gilt insbesondere in Bezug auf die im Vergleich zu nicht verteilten Systemen erzielbare höhere Widerstandsfähigkeit eines Gesamtsystems gegenüber Fehlern wie den Ausfällen ganzer Rechner oder sogar kompletter Datenzentren. Ausgehend von den einfachsten, aus nur einem Client und einem Server bestehenden verteilten Systemen, beschäftigt sich die Vorlesung danach mit der deutlich komplexeren Replikation der Server-Seite und behandelt anschließend die Verteilung eines Systems über mehrere, mitunter weit voneinander entfernte geografische Standorte. In allen Abschnitten umfasst die Betrachtung des jeweiligen Themas eine Auswahl aus Grundlagen, im Praxiseinsatz befindlicher Ansätze und Techniken sowie für den aktuellen Stand der Forschung repräsentativer Konzepte. Im Rahmen der Übungen wird zunächst ein plattformunabhängiges Fernaufrufsystem schrittweise entwickelt und parallel dazu getestet. Als Vorlage und Orientierungshilfe dient dabei das in der Praxis weit verbreitete Java RMI. In den weiteren Übungsaufgaben stehen anschließend klassische Problemstellungen von verteilten Systemen

		wie fehlertolerante Replikation und verteilte Synchronisation im Mittelpunkt.
6	Learning objectives and skills	Studierende, die das Modul erfolgreich abgeschlossen haben: • beschreiben charakteristische Merkmale und Eigenschaften verteilter Systeme sowie grundlegende Probleme im Zusammenhang mit ihrer Realisierung. • untersuchen die Unterschiede zwischen lokalen Methodenaufrufen und Fernmethodenaufrufen. • vergleichen Ansätze zur Konvertierung von Nachrichten zwischen verschiedenen Datenrepräsentationen. • konzipieren eine eigene auf Java RMI basierende Anwendung. • entwickeln ein eigenes Fernaufrufsystem nach dem Vorbild von Java RMI. • gestalten ein Modul zur Unterstützung verschiedener Fernaufrufsemantiken (Maybe, Last-of-Many) für das eigene Fernaufrufsystem. • beurteilen auf Basis eigener Experimente mit Fehlerinjektionen die Auswirkungen von Störeinflüssen auf verschiedene Fernaufrufsemantiken. • klassifizieren Mechanismen zur Bereitstellung von Fehlertoleranz, insbesondere verschiedene Arten der Replikation (aktiv vs. passiv). • vergleichen verschiedene Konsistenzgarantien georeplizierter Systeme. • illustrieren das Problem einer fehlenden gemeinsamen Zeitbasis in verteilten Systemen. • erforschen logische Uhren als Mittel zur Reihenfolgebestimmung und Methoden zur Synchronisation physikalischer Uhren. • unterscheiden grundlegende Zustellungs- und Ordnungsgarantien beim Multicast von Nachrichten. • gestalten ein Protokoll für den zuverlässigen und totalgeordneten Versand von Nachrichten in einer Gruppe von Knoten. • entwickeln einen Dienst zur Verwaltung verteilter Sperrobjekte auf Basis von Lamport-Locks. • bewerten die Qualität einer Publikation aus der Fachliteratur. • erschließen sich typische Probleme (Nebenläufigkeit, Konsistenz) und Fehlerquellen bei der Programmierung verteilter Anwendungen. • können in Kleingruppen kooperativ arbeiten. • können ihre Entwurfs- und Implementierungsentscheidungen kompakt präsentieren und argumentativ vertreten. • können offen und konstruktiv mit Schwachpunkten und Irrwegen umgehen. • reflektieren ihre Entscheidungen kritisch und leiten Alternativen ab.
7	Prerequisites	Gute Programmierkenntnisse in Java

8	Integration in curriculum	semester: 5
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination Das Modul wird bestanden bei erfolgreicher Bearbeitung aller 6 Übungsaufgaben (Bewertung jeweils mit "ausreichend") und dem Bestehen einer 30-minütigen mündlichen Prüfung.
11	Grading procedure	Written examination (100%) Die Modulnote ergibt sich zu 100% aus der Bewertung der mündlichen Prüfung.
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	

1	Module name 47800	Digital Communications Digital communications	5 ECTS
2	Courses / lectures	Vorlesung: Digital Communications (3 SWS) Übung: Tutorial for Digital Communications (1 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Laura Cottatellucci Brikena Kaziu	

4	Module coordinator	Prof. Dr. Laura Cottatellucci
5	Contents	Alle modernen Kommunikationssysteme basieren auf digitalen Übertragungsverfahren. Diese Vorlesung befasst sich mit den Grundlagen der Analyse und des Entwurfs digitaler Sender und Empfänger. Dabei wird zunächst von einem einfachen Kanalmodell bei dem das Empfangssignal nur durch additives weißes Gaußsches Rauschen gestört wird ausgegangen. Im Verlauf der Vorlesung werden aber auch Kanäle mit unbekannter Phase sowie verzerrende Kanäle betrachtet. Behandelt werden unter anderem digitale Modulationsverfahren (z.B. Pulsamplitudenmodulation (PAM), digitale Frequenzmodulation (FSK), und Kontinuierliche-Phasenmodulation (CPM)), Orthogonalkonstellationen, das Nyquistkriterium in Zeit- und Frequenzbereich, optimale kohärente und inkohärente Detektions- und Decodierungsverfahren, die Signalraumdarstellung digital modulierter Signale, verschiedene Entzerrungsverfahren, und Mehrträger-Übertragungsverfahren. --- Modern communication systems are based on digital transmission methods. This course covers basics of analysis and design of digital transmitters and receivers. Initially, we consider a simple channel model whose received signal is impaired only by additive white Gaussian noise. Then, we extend fundamental concepts to channels with unknown phases and distortion. Additionally, we treat digital modulation techniques, e.g., pulse amplitude modulation (PAM), digital frequency modulation (FSK) and continuous-phase modulation (CPM), and orthogonal constellations. The Nyquist criterion in time and frequency domain, optimal coherent and incoherent detection and decoding methods, signal space representations of digitally modulated signals, various equalization methods, and multicarrier transmission methods are also discussed.
6	Learning objectives and skills	Die Studierenden - analysieren und klassifizieren digitale Modulationsverfahren hinsichtlich ihrer Leistungs- und Bandbreiteneffizienz sowie ihres Spitzenwertfaktors, - ermitteln notwendige Kriterien für impulsinterferenzfreie Übertragung, - charakterisieren digitale Modulationsverfahren im Signalraum, - ermitteln informationsverlustfreie Demodulationsverfahren, - entwerfen optimale kohärente und inkohärente Detektions- und Decodierungsverfahren,

		• vergleichen verschiedene Entzerrungsverfahren hinsichtlich deren Leistungsfähigkeit und Komplexität, • entwerfen einfache digitale Übertragungssysteme mit vorgeschriebenen Leistungs- und Bandbreiteneffizienzen sowie Spitzenwertfaktoren. • -- The students • analyze and classify digital modulation techniques in terms of performance and bandwidth efficiency as well as crest factor, • determine necessary criteria to design impulses for interference-free transmission, • characterize digital modulation methods in signal space, • determine information loss-free demodulation methods, • design optimal coherent and incoherent detection and decoding methods, • compare different equalization methods in terms of performance and complexity, • design simple digital transmission systems with prescribed power and bandwidth efficiency and crest factor.
7	Prerequisites	None
8	Integration in curriculum	semester: 5
9	Module compatibility	Networking & Collaboration - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 48410	Information Theory and Coding Information theory and coding	5 ECTS
2	Courses / lectures	Übung: Tutorial for Information Theory and Coding (1 SWS) Vorlesung: Information Theory and Coding (3 SWS)	- 5 ECTS
3	Lecturers	Dr. Sebastian Lotter	

4	Module coordinator	Prof. Dr.-Ing. Ralf Müller
5	Contents	1. Introduction: binomial distribution, (7,4)-Hamming code, parity-check matrix, generator matrix 2. Probability, entropy, and inference: entropy, conditional probability, Bayes law, likelihood, Jensens inequality 3. Inference: inverse probability, statistical inference 4. The source coding theorem: information content, typical sequences, Chebychev inequality, law of large numbers 5. Symbol codes: unique decidability, expected codeword length, prefix-free codes, Kraft inequality, Huffman coding 6. Stream codes: arithmetic coding, Lempel-Ziv coding, Burrows-Wheeler transform 7. Dependent random variables: mutual information, data processing lemma 8. Communication over a noisy channel: discrete memory-less channel, channel coding theorem, channel capacity 9. The noisy-channel coding theorem: jointly-typical sequences, proof of the channel coding theorem, proof of converse, symmetric channels 10. Error-correcting codes and real channels: AWGN channel, multivariate Gaussian pdf, capacity of AWGN channel 11. Binary codes: minimum distance, perfect codes, why perfect codes are bad, why distance isnt everything 12. Message passing: distributed counting, path counting, low-cost path, min-sum (=Viterbi) algorithm 13. Exact marginalization in graphs: factor graphs, sum-product algorithm 14. Low-density parity-check codes: density evolution, check node degree, regular vs. irregular codes, girth 15. Lossy source coding: transform coding and JPEG compression -- 1. Einleitung: Binomialverteilung, (7,4)-Hamming-Code, Paritätsmatrix, Generatormatrix 2. Wahrscheinlichkeit, Entropie und Inferenz: Entropie, bedingte Wahrscheinlichkeit, Bayessches Gesetz, Likelihood, Jensensche Ungleichung 3. Inferenz: Inverse Wahrscheinlichkeit, statistische Inferenz 4. Das Quellencodierungstheorem: Informationsgehalt, typische Folgen, Tschebyschevsche Ungleichung, Gesetz der großen Zahlen 5. Symbolcodes: eindeutige Dekodierbarkeit, mittlere Codewortlänge, präfixfreie Codes, Kraftsche Ungleichung, Huffmancodierung

		6. Stromcodes: arithmetische Codierung, Lempel-Ziv-Codierung, Burrows-Wheeler-Transformation 7. Abhängige Zufallsvariablen: Transinformation, Datenverarbeitungslemma 8. Kommunikation over gestörte Kanäle: diskreter gedächtnisloser Kanal, Kanalcodierungstheorem, Kanalkapazität 9. Das Kanalcodierungstheorem: verbundtypische Folgen, Beweis des Kanalcodierungstheorems, Beweis des Umkehrsatzes, symmetrische Kanäle 10. Fehlerkorrigierende Codes und reale Kanäle: AWGN-Kanal, mehrdimensionale Gaußsche WDF, Kapazität des AWGN-Kanals 11. Binäre Codes: Minimaldistanz, perfekte Codes, Warum perfekte Codes schlecht sind, Warum Distanz nicht alles ist 12. Nachrichtenaustausch: verteiltes Zählen, Pfadzählen, günstigster Pfad, Minimumsummenalgorithmus 13. Exakte Marginalisierung in Graphen: Faktorgraph, Summenproduktalgorithmus 14. LDPC-Codes: Dichteevolution, Knotenordnung, reguläre und irreguläre Codes, Graphumfang 15. Verlustbehaftete Quellencodierung: Transformationscodierung und JPEG-Kompression
6	Learning objectives and skills	The students apply Bayesian inference to problems in both communications and everyday's life. The students explain the concept of digital communications by means of source compression and forward-error correction coding. For the design of communication systems, they use the concepts of entropy and channel capacity. They calculate these quantities for memoryless sources and channels. The students proof both the source coding and the channel coding theorem. The students compare various methods of source coding with respect to compression rate and complexity. The students apply source compression methods to measure mutual information. The students factorize multivariate functions, represent them by graphs, and marginalize them with respect to various variables. The students explain the design of error-correcting codes and the role of minimum distance. They decode error-correcting codes by means of maximum-likelihood decoding and message passing. The students apply distributed algorithms to problems in both communications and everyday's life. The students improve the properties of low-density parity-check codes by widening the girth and/or irregularity in the degree distribution. The students transform source images into the frequency domain to improve lossy compression. -- Die Studierenden wenden Bayessche Inferenz auf Probleme in der Nachrichtentechnik und im Alltagsleben an.

		Die Studierenden erklären die konzeptuelle Trennung von digitaler Übertragung in Quellen- und Kanalcodierung. Kommunikationssysteme entwerfen sie unter Betrachtung von Entropie und Kanalkapazität. Sie berechnen diese Größen für gedächtnislose Quellen und Kanäle. Die Studierenden beweisen sowohl das Quellen- als auch das Kanalcodierungstheorem. Die Studierenden vergleichen verschiedenartige Quellencodierungsverfahren hinsichtlich Komplexität und Kompressionsrate. Die Studierenden verwenden Quellencodierverfahren zur Messung von Transinformation. Die Studierenden faktorisieren Funktionen mehrerer Veränderlicher, stellen diese als Graph dar und marginalisieren sie bezüglich mehrerer Veränderlicher. Die Studierenden erklären den Entwurf von Kanalcodes und den Einfluss der Minimaldistanz. Sie decodieren Kanalcodes gemäß maximaler Likelihood und Nachrichtenaustausch. Die Studierenden wenden verteilte Algorithmen auf Probleme der Nachrichtentechnik und des Alltagslebens an. Die Studierenden verbessern die Eigenschaften von LDPC-Codes durch Erhöhung des Umfangs und/oder durch irreguläre Knotenordnungsverteilungen. Die Studierenden transformieren Bildquellen zur Verbesserung verlustbehafteter Kompression in den Frequenzbereich.
7	Prerequisites	None
8	Integration in curriculum	semester: 5;6
9	Module compatibility	Networking & Collaboration - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Die Prüfung besteht aus einem 120-minütigen schriftlichen Test. The examination is a 120-minute written test.
11	Grading procedure	Written examination (100%)
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	MacKay, D.: Information Theory, Inference, and Learning Algorithms, Cambridge University Press, Cambridge, 2003.

1	Module name 96300	MIMO Communication Systems MIMO communication systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Robert Schober
5	Contents	Modern communication systems employ multiple antennas at the transmitter and/or receiver creating a multiple-input multiple-output (MIMO) system. This course covers the fundamental mathematical and communication theoretical concepts necessary for the design and analysis of MIMO communication systems. Relevant topics include MIMO Channel Capacity, Receive Diversity, Transmit Diversity, Space-Time Coding, Spatial Multiplexing, MIMO Transceiver Design, Multi-user MIMO, Massive MIMO, Relay-based MIMO, and applications in modern communication systems.
6	Learning objectives and skills	The students • learn about different MIMO channel models, • analyze MIMO communication systems with respect to their channel capacity and reliability, • determine MIMO figures of merit such as coding gain, diversity gain, and multiplexing gain, • compare and evaluate different MIMO receiver designs, • characterize the rate region of multiuser systems, • analyze massive MIMO systems, • discuss the advantages and disadvantages of different relay network architectures. Die Studierenden • lernen verschiedene MIMO-Kanalmodelle kennen, • analysieren MIMO-Kommunikationssysteme hinsichtlich der Kanalkapazität und Zuverlässigkeit, • ermitteln MIMO-Kenngrößen wie Codierungsgewinn, Diversitätsgewinn und Multiplexgewinn, • vergleichen und beurteilen verschiedene MIMO-Empfangsstrategien, • charakterisieren die Ratenregion von Mehrteilnehmersystemen, • analysieren Massive-MIMO-Systeme, • diskutieren die Vor- und Nachteile verschiedener Relaisnetzwerkarchitekturen.
7	Prerequisites	Basic course in communications
8	Integration in curriculum	semester: 6
9	Module compatibility	Networking & Collaboration - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242

10	Method of examination	Written or oral (90 minutes) Written exam (Klausur), 90 minutes.
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 668129	Machine Learning in Communications Machine learning in communications	5 ECTS
2	Courses / lectures	Vorlesung: Machine Learning in Communications (4 SWS) Übung: Tutorial for Machine Learning in Communications (0 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Laura Cottatellucci Christian Forsch	

4	Module coordinator	Prof. Dr. Laura Cottatellucci
5	Contents	Recently, in many areas of wireless communications such as wireless sensor networks (WSNs), heterogeneous networks and complex ad hoc networks, distributed graph algorithms and machine learning on graphs are gaining relevance as fundamental tools in network analysis and information processing. This motivates to deliver a general introduction to fundamentals of machine learning such as detection of clusters on graphs. The introduction is followed by the application of machine learning to the design of physical and data layer techniques in wireless communications and in the optimization of mobile networks.
6	Learning objectives and skills	The students • know and explain the fundamentals of machine learning with special attention to machine learning over graphs. • apply these principles in the design and optimisation of wireless communications systems and mobile networks.
7	Prerequisites	None
8	Integration in curriculum	semester: 5
9	Module compatibility	Networking & Collaboration - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral The examination is a 30-minute oral exam. The examination language is English.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 700506	Communications Systems Design Communications systems design	5 ECTS
2	Courses / lectures	Vorlesung: Communications Systems Design (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Georg Fischer	

4	Module coordinator	Prof. Dr.-Ing. Georg Fischer Prof. Dr.-Ing. Norman Franchi Torsten Reißland Torsten Reißland
5	Contents	Learning based on LabVIEW communications and NI USRP: Introduction to USRP including hardware blocks of Tx/Rx chains Getting familiar with LabVIEW communications environment and controlling VIs (Panel, diagram, etc.) and fundamentals of LabVIEW programming: data types, arrays, flow control (for/while loop), clusters, case structures, signal sources, sinks, signal processing tools, filters, time/ frequency domain analysis, etc. Transmission and reception of analog modulation schemes: AM/DSB-SC and FM Implementation of digital modulation schemes: ASK, FSK, BPSK, QPSK, 16-QAM, etc. Digital Tx/Rx: symbol mapping, upsampling/downsampling, pulse shaping (rectangular, Gaussian, RRC), matched filtering, pulse alignment, synchronization, and detection Phase synchronization, FDM and image rejection algorithm Eye diagram analysis: ISI, clock jitter, optimal sampling time, detection threshold Power control for over-the-air transmission in sub-6 GHz ISM bands and analysis on fading and multipath propagation effects Channel estimation, equalization (decision directed, linear LS, adaptive LMS), modelling: coherence bandwidth and propagation delay Learning based on MATLAB and USRPs (Communications toolbox and SDR support packages): OFDM Tx/Rx with frequency domain equalization (FDE) and synchronization (training sequence and frame detection) LTE downlink transmission (MIMO) including system information blocks (SIB) and spectrum analysis including estimation/calibration of carrier frequency offset (CFO) Impairments/distortion analysis: ACPR, EVM tool: IQ offset errors, phase noise, PA nonlinearity, etc. Learning based on GNU Radio and RTL-SDR: Introduction to GNU Radio with RF prototyping demonstration Spectrum analyzer implementation: RBW, VBW, sweep time, and phase noise Small Project/assignment for students
6	Learning objectives and skills	Students Can bridge the gap between communications theory, analog/digital baseband, and RF design

		Can develop quick and flexible prototypes for real-time communications systems and standards using SDR solutions Can determine the design parameters and assess the interaction between various analog and digital parts Can create efficient Tx/Rx programs and signal processing algorithms in LabVIEW, MATLAB, and GNU Radio Can implement channel estimation and equalization algorithms in TDD and FDD systems Can demonstrate MIMO and OFDM based systems like LTE and beyond Can quantify and evaluate system performance using EVM and impairments analysis
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 45 h Independent study: 30 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 636348	Cyber-Physical Systems Cyber-physical systems	5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Dr.-Ing. Torsten Klie
5	Contents	Klassische Computersysteme zeichnen sich durch eine strikte Trennung von realer und virtueller Welt aus. Moderne Steuerungssysteme, die z.B. in modernen Fahrzeugen verbaut sind und die aus einer Vielzahl von Sensoren und Aktoren bestehen, entsprechen diesem Bild nur sehr eingeschränkt. Diese Systeme, oft "Cyber-Physical Systems (CPS)" genannt, erkennen ihre physische Umgebung, verarbeiten diese Informationen und können die physische Umwelt auch koordiniert beeinflussen. Hierzu ist eine starke Kopplung von physischem Anwendungsmodell und dem Computer-Steuerungsmodell nötig. Im Unterschied zu Eingebetteten Systemen bestehen CPS meist aus vielen vernetzten Komponenten, die sich selbständig untereinander koordinieren. Diese Vorlesung spannt den Bogen von kontrolltheoretischen Grundlagen über Selbstorganisationsprinzipien bis hin zu visionären Anwendungen aus den Bereichen Verkehr und Medizintechnik. Ferner werden Entwurfsmethoden für Cyber-Physical Systems vorgestellt.
6	Learning objectives and skills	Die Studierenden erläutern, was Cyber-Physical Systems sind und auf welchen technologischen Grundlagen sie aufbauen, insbesondere in den Bereichen Regelungstechnik, Ablaufplanung, Kommunikation und Selbstorganisation bewerten CPS in verschiedenen Anwendungsgebieten stellen den Entwurfsprozess von CPS dar, insbesondere die Modellierung und die grundlegende Programmierung entdecken wesentliche Herausforderungen beim Entwurf, Ausbringung und Einsatz von CPS.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h

14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	• Andrea Bondavalli, Sara Bouchenak und Hermann Kopetz (Hrsg.) Cyber-Physical Systems of Systems: Foundations – A Conceptual Model and Some Derivations: The AMADEOS Legacy. Springer 2016. • Otto Föllinger Regelungstechnik. Hüthig 1992. • Hilmar Jaschek und Holger Voos Grundkurs der Regelungstechnik. Oldenbourg 2010. • Jörg Kahlert Crash-Kurs Regelungstechnik. VDE Verlag 2010. • Peter Marwedel Embedded Systems Design – Embedded Systems Foundations of Cyber-Physical Systems, and the Internet of Things, 4. Auflage. Springer 2021 • André Platzner Logic Foundations of Cyber-physical Systems. Springer 2018. • Wolfgang Schneider Praktische Regelungstechnik. Vieweg +Teubner 2008. • Walid M. Taha, Abd-Ehamid M. Taha und Johan Thunberg Cyber-physical Systems – A Model-based Approach. Springer 2021.

1	Module name 43141	Mobile Communications Mobile communications	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Ralf Müller
5	Contents	History of mobile communications, cellular systems, sectorization, spectral efficiency, co-channel interference, adjacent-channel interference, near-far effect, cellular network architecture, antenna types and parameters, free space propagation, reflection, attenuation, diffraction, scattering, classification of channel models, ground reflection model, Okumura-Hata model, shadowing, narrow-band fading, time-variant channels, scattering function, delay-Doppler spectrum, diversity principles, combining methods, diversity gain, multiplexing, duplexing, digital modulation, Gaussian filtered minimum shift keying, basics of channel coding, interleaving, global system for mobile communications, physical versus logical channels, frame structure, call set-up, synchronization, channel estimation, hand-off
6	Learning objectives and skills	The students explain the cellular structure of mobile communication systems. They students explain the physical mechanics of radio wave propagation in the cm-band. The students explain the GSM cellular communications standard. The students discuss the pros and cons of several multiple-access and duplexing methods. The students discuss the pros and cons of several modulation and coding formats. The students decide which antenna type is suitable for a given morphological structure of the environment. The students predict the amplitude and dynamic of the attenuation between a mobile transmitter and a fixed receiver. The students utilize diversity methods to improve the link quality. The students determine the coverage probability of a given cellular communication system. The students collaborate on solving exercise problems. The students discuss which system solutions fit to which environments.
7	Prerequisites	None
8	Integration in curriculum	semester: 2
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h

14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Proakis, J.: Digital Communications, McGraw-Hill, 4th ed., 2001. Rappaport, T.: Wireless Communications: Principles & Practice, Prentice Hall, 2nd ed., 2001. Mouly, M., Paulet, M.: The GSM System for Mobile Communications, Cell & SYS, France, 1992. Goldsmith, A.: Wireless Communications, Cambridge Univ. Press, 2005.

1	Module name 687141	Multiusuer Information and Communications Theory Multiuser information and communications theory	5 ECTS
2	Courses / lectures	Übung: Tutorial for Multiuser Information and Communications Theory (1 SWS) Vorlesung: Multiuser Information and Communications Theory (3 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr.-Ing. Ralf Müller	

4	Module coordinator	Prof. Dr.-Ing. Ralf Müller
5	Contents	Linear vs. nonlinear multiple-access, CDMA as a canonical framework for any multiple-access schemes, optimum multiuser detection, linear multiuser detection, interference cancellation, rate region, multiuser source coding, time sharing, multiuser channel codes, multiple-access channel (MAC), capacity region, mutual information versus minimum-mean squared error, Gaussian MAC, power region, Gaussian vector MAC, source coding with side information, degraded broadcast channel, Gaussian broadcast-MAC duality, Gaussian vector broadcast channel, dirty-paper coding, physically degraded relay channel, scalar Gaussian relay channel, Gaussian interference channel, cut-set bound, network coding, fading channels, multiuser water filling, block fading, diversity, user diversity, capacity versus outage, near-far gain, dual antenna arrays
6	Learning objectives and skills	The students model any multiple access method as a special case of code-division multiple access. The students apply various algorithms for multiuser detection. The students explain various types of multiuser channels and their limits to transport information. The students explain the limits of distributed source coding algorithms. The students apply the cut-set bound. The students explain the method of dirty-paper coding. The students collaborate on solving exercise problems.
7	Prerequisites	Recommended: A basic course on information theory (can be taken in parallel)
8	Integration in curriculum	semester: 6
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral The examination is a 30-minute oral exam.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester

15	Teaching and examination language	english
16	Bibliography	• El Gamal, A., Kim, Y.: Network Information Theory, Cambridge University Press, 2011 • Cover, T., Thomas, J.: Elements of Information Theory, 2nd ed., Wiley, Hoboken, 2006 • Verdú, S.: Multiuser Detection, Cambridge Univ. Press, Cambridge, 1998 • Tse, D., Viswanath, P.: Fundamentals of Wireless Communications, Cambridge University Press, 2005.

1	Module name 451971	Random Matrices in Communications and Signal Processing Random matrices in communications and signal processing	5 ECTS
2	Courses / lectures	Vorlesung: Random Matrices in Communications and Signal Processing (2 SWS) Übung: Tutorial for Random Matrices in Communications and Signal Processing (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Ralf Müller	

4	Module coordinator	Prof. Dr.-Ing. Ralf Müller
5	Contents	Dual antenna arrays, compressive sensing, Wishart distribution, factor iid model, Kronecker model, convergence of random variables, semi-circle law, quarter circle law, full circle law, Haar distribution, Marchenko-Pastur distribution, Stieltjes transform, Girkos law, unitary invariance, freeness, free convolution, R-transform, free central limit theorem, free Poisson limit theorem, subordination, S-transform, R-diagonal random matrices, R-diagonal free convolution, Haagerup-Larsen law, operator-valued freeness, linearization of noncommutative polynomials, free Fourier transform, self-averaging properties, microscopic vs. macroscopic random variables, quenched random variable, a statistical physics point of view of digital systems, spin glasses, frozen disorder, replica method, replica continuity, replica symmetry, replica symmetry breaking, approximate message passing, classification of np-complete problems
6	Learning objectives and skills	The students find the limiting eigenvalue distributions of various types of random matrices. The students explain Stieltjes, R- and S-transforms. The students explain the limits of various types of fading channels. The students design coding and decoding methods for a given type of multiuser channel. The students perform additive and multiplicative free convolution. The students calculate the asymptotic eigenvalues distributions of given random matrix ensembles. The students construct random matrix ensembles with a given eigenvalue distribution. The students linearize matrix polynomials. The students derive the Boltzmann distribution. The students utilize saddle point integration. The students perform replica calculations. The students explain the meaning of replica symmetry breaking. The students collaborate on solving exercise problems.
7	Prerequisites	Recommended: Good skills in linear algebra, probability theory and complex analysis
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242

		Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral The examination is a 30-minute oral exam.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• Mingo, J., Speicher, R.: Free Probability and Random Matrices, Springer, 2017 • Couillet, R., Debbah, M.: Random Matrix Methods for Wireless Communications, Cambridge Univ. Press, Cambridge, 2011. • Mezard, M., Montanari, A.: Information, Physics, and Computation, Oxford Graduate Texts, 2009.

1	Module name 412023	Channel Coding on Graphs Channel coding on graphs	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Laura Cottatellucci
5	Contents	*Description* In today's communications world, channel coding underlies the physical layer of all major communication systems. For example: algebraic block coding (Reed-Solomon codes) are used in the CD and DVD standards; trellis coded modulation is used in line modems; low-density parity check codes (LDPC) are used in satellite communications (DVB-S2 standard), LAN (10GBase-T Ethernet) and wireless LAN (Wi-Fi 802.11); turbo codes are implemented in 3G/4G mobile communications (e.g. in UMTS and LTE) and in (deep space) satellite communications. Recently, polar codes have been adopted for the eMBB (Enhanced Mobile Broadband) control channels for the 5G NR (5th Generation New Radio) interface. Objective of this course is to provide an introductory but thorough background on codes over graphs and covers both classical convolutional codes and the modern theory of random-like codes with iterative decoding. Namely, LDPCs (Low Density Parity Check Codes, Turbo Codes, and Polar Codes. Students will acquire the fundamental knowledge to design and analyze performance of channel codes on graphs, as well as implement the corresponding encoders and decoders. *Technical Content* • Role of channel coding in a communication system. • Idealized channel models : the binary symmetric channel (BSC), the binary erasure channel (BEC), the constrained-input Gaussian channel. • Some preliminary basic concepts from linear block codes: Parity Check, Hamming distance, weight enumerating functions, performance evaluations, and performance bounds. • Factor graphs and belief propagation. • Binary random-like codes: LDPC codes and message-passing decoding, threshold behaviour of message passing decoding: density evolution analysis. Design of LDPC ensembles. • Polar Codes: Polarization, polar channel coding, performance, encoding and decoding. • Binary convolutional codes : the algebraic structure, the dynamic structure, Viterbi decoding, performance analysis via weight enumerating function, the forward-backward algorithm. • Other random-like codes: the Turbo Codes. Efficient decoding of Turbo Codes via forward-backward algorithm and interpretation via factor graphs. Performance analysis and exit charts.

6

Learning objectives and skills

The student

Uses idealized channel models (the binary symmetric channel (BSC), the binary erasure channel (BEC), the constrained-input

Gaussian channel) to compute their capacities

Contrasts soft output decoders with disjoint detection and decoding, maximum likelihood and maximum a posteriori decoders

Relates the concepts of Parity Check, Hamming distance, weight enumerating functions to the performance analysis of codes on graphs

Devises factor graphs of proposed communication systems

Assesses and justifies the applicability of belief propagation to given factor graphs

Assesses and justifies the applicability of message passing to codebooks defined in terms of Tanner graph or parity check matrix

Applies message passing to codebooks defined in terms of Tanner graph or parity check matrix

Analyses the performance of LDPC code decoding via density evolution

Computes exit charts for LDPC codes for the equations of the density evolution

Designs LDPC ensemble for a given channel to maximize the code rate

Justifies the design of LDPC codes via design of LDPC ensembles

Interprets convolutional codes as linear block codes

Compares algebraic and dynamic representations of convolutional codes

Computes steps of the Viterbi algorithm

Summarizes and justifies the fundamental structure of the Viterbi algorithm

Computes steps of the BCJR algorithm

Summarizes and justifies the fundamental structure of BCJR algorithm

Compares Viterbi and BCJR algorithms

Justifies low complexity and/or practical implementations of the Viterbi and the BCJR algorithm

Attaches a direct graph to a convolutional code and computes its transfer function

Assesses the performance of the Viterbi decoder via (bit) weight enumerating function based on the transfer function method

Interprets a BCJR algorithm as message passing over a factor graph

Combines encoders of convolutional codes to generate parallel concatenated codes with interleaver (turbo codes) of given rate

Combines encoders of convolutional codes to generate serial concatenated codes with interleaver (turbo codes)

Compares the key features of parallel concatenated codes with interleaver (turbo codes) to serial concatenated codes with interleaver (turbo codes)

Designs decoders for turbo codes utilizing coupled BCJR-based decoders for convolutional codes

Interprets turbo decoders as factor graphs and justifies their implementation via message passing

Assesses the performance of turbo codes using exit charts

		Formulates the concept of source polarization and relates it to polar channel coding Interprets polar channel coding as factor graphs Designs polar channel codes Argues about capacity achievability of polar channel codes
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes) Oral exam, 30 minutes
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 151664	Advanced Communication Networks Advanced communication networks	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Laura Cottatellucci
5	Contents	Telecommunications have become ubiquitous in daily life and wireless networks play a fundamental role thanks to their capability to support mobility. In a wireless communication, the concept of link does not exist. Users radiate energy and communicate through the superposition of each others transmissions which creates interference. Compared to wireline networks this scenario is extremely challenging but also offers unpredictable opportunities in the development of new technologies (massive MIMO, cognitive radio, etc.) and exploitation of new features, e.g., opportunistic communications and multiuser diversity. The exponentially increasing request of higher and higher throughput is satisfied densifying users and access points per unit area and allowing more and more interference while adopting advanced techniques and innovative resource allocation to mitigate the detrimental effects of interference. Objective of this course is to introduce the student to advanced techniques for coordinated medium access control and radio resource management in cellular systems. Power allocation, rate adaptation and scheduling will be discussed both in centralized and distributed settings. Some mathematical methods play a fundamental role in resource allocation, namely, classical Perron-Frobenius theory for nonnegative matrices, convex and nonconvex constrained optimization, distributed optimization and game theory. The course introduces the student to such methods and exemplifies their application to various resource allocation problems. Additionally, the course addresses relevant aspects of resource allocation in wireless networks such as fairness and cross-layer design. *Technical Content* • Properties and challenges of the wireless medium. • Basic concepts of communication networks: the layered architecture. • Evolution of wireless cellular network architectures: From Global System for Mobile to Advanced-Long Term Evolution. • Multiple Access Schemes: CSMA variants, TDMA, FDMA, CDMA, OFDMA, SC-FDMA, SDMA. • Uplink-downlink duality. • Opportunistic scheduling and multiuser diversity. • Advanced concepts: small cells and heterogeneous networks, relaying and cooperation, network coding, cognitive radio networks. • Basics of resource allocation: power allocation, rate adaptation, and scheduling.

		• Classical resource allocation techniques: Centralized and distributed power control based on the Perron-Frobenius theorem. • Fundamentals of convex constrained optimization and application to resource allocation. • Resource allocation and fairness. • Fundamentals of nonconvex optimization and relaxation techniques. • Applications of nonconvex optimization to resource allocation. • Fundamentals of distributed optimization and applications to resource allocation. • Fundamental concepts of game theory. • Resource contention via game theoretical methods.
6	Learning objectives and skills	The student • Describes and/or recognizes wireless channel models. • Criticizes the limits of a layered architecture in wireless systems. • Defends the use of cross-layer design in wireless network. • Appraises and compares the distribution of functionalities in network entities for different architectures. • Argue on the pros and contras of different multiple access schemes according to various criteria (e.g. spectral efficiency, power efficiency, robustness to interference). • Compares and contrasts micro-diversity and various macro-diversity schemes. • Computes the total rate of SDMA with various receivers. • Relates the multiple access in uplink to broadcasting in downlink and justifies the concept of uplink-downlink duality. • Uses uplink-downlink duality to design a precoder and allocate power. • Contrasts multiple access in uplink and broadcasting in downlink in terms of channel state acquisition both for TDD and FDD transmission. • Uses multiuser diversity for opportunistic scheduling. • Compares multiuser diversity for users having identical and different channel statistics. • Contrasts opportunistic scheduling in terms of channel state acquisition and feedback both for uplink and downlink and for both FDD and TDD transmission schemes. • Appraises the impact of multiple antennas on opportunistic scheduling. • Analyses different settings with interference in small cells and designs countermeasures. • Categorizes relaying schemes in LTE. • Analyses performance of relaying schemes. • Argues on possible improvements of relaying schemes via network coding and physical layer network coding. • Uses the Perron-Frobenius theorem to allocate power in a centralized manner.

		• Judges the feasibility of a power control problems and formulates alternative approaches in case of unfeasibility. • Uses the Perron-Frobenius theorem to design a distributed power control scheme. • Judges the convergences of distributed power control based on the Perron-Frobenius theorem and appraises the robustness of asynchronous power control. • Applies techniques of convex optimization to discriminate convex problems and determine necessary and/or sufficient conditions for global optimality. • Judges the applicability of KKT conditions and duality. • Uses KKT conditions to solve convex optimization problems. • Uses duality to solve convex optimization problems. • Applies convex optimization to resource allocation in wireless communications. • Compares different definitions of fairness and applies them to rate allocation. • Appraises the effect of channel knowledge at the transmitter on different fairness criteria. • Applies KKT conditions for opportunistic user scheduling. • Describes a proportional fair algorithm for opportunistic scheduling. • Applies relaxation to nonconvex quadratic constrained quadratic programming. • Formulates resource allocation problems as constrained optimization programming. • Contrasts various distributed optimization methods. • Applies the concept of best response to determine Nash equilibria. • Argues about existence and uniqueness of Nash equilibria. • Assesses if a given game is a potential game and solves it. • Defends the concept of Pareto optimality in resource allocation. • Contrasts the concepts of pure and mixed strategies in game theory. • Uses coupled constrained concave game to allocate powers in heterogeneous networks.
7	Prerequisites	Information Theory and Coding It is advisable that the student is familiar with basic concepts of Mobile Communications
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes) Oral exam, 30 minutes

11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 96850	Convex Optimization in Communications and Signal Processing Convex optimization in communications and signal processing	5 ECTS
2	Courses / lectures	Übung: Tutorial for Convex Optimization in Communications and Signal Processing (1 SWS) Vorlesung: Convex Optimization in Communications and Signal Processing (3 SWS)	- 5 ECTS
3	Lecturers	Yifei Wu apl. Prof. Dr. Wolfgang Gerstacker	

4	Module coordinator	apl. Prof. Dr. Wolfgang Gerstacker
5	Contents	Convex optimization problems are a special class of mathematical problems which arise in a variety of practical applications. In this course we focus on the theory of convex optimization, corresponding algorithms, and applications in communications and signal processing (e.g. statistical estimation, allocation of resources in communications networks, and filter design). Special attention is paid to recognizing and formulating convex optimization problems and their efficient solution. The course is based on the textbook "Convex Optimization" by Boyd and Vandenberghe and includes a tutorial in which many examples and exercises are discussed.
6	Learning objectives and skills	Students • characterize convex sets and functions, • recognize, describe and classify convex optimization problems, • determine the solution of convex optimization problems via the dual function and the KKT conditions, • apply numerical algorithms in order to solve convex optimization problems, • apply methods of convex optimization to different problems in communications and signal processing
7	Prerequisites	Signals and Systems, Communications
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written or oral (90 minutes) Die Prüfung ist eine 90-minütige schriftliche Klausur. Prüfungssprache ist Englisch. The examination is a 90-minute written test. The examination language is English.
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in winter semester

13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Boyd, Steven ; Vandenberghe, Lieven: Convex Optimization. Cambridge, UK : Cambridge University Press, 2004

1	Module name 43420	Transmission and Detection for Advanced Mobile Communications Transmission and detection for advanced mobile communications	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	apl. Prof. Dr. Wolfgang Gerstacker
5	Contents	The aim of this lecture is that the students acquire a basic knowledge of advanced transmission and detection techniques which are relevant to practical mobile communications systems. In the first part, it is shown how equalization schemes like decision-feedback equalization (DFE) and maximum-likelihood sequence estimation (MLSE) can be applied to the GSM/EDGE (Enhanced Data Rates for GSM Evolution) standard. Also, channel estimation for GSM/EDGE is covered. In GSM/EDGE, disturbance by interfering signals of other users is a further major problem. Therefore, interference cancellation algorithms are discussed in detail. The cases of several receive antennas and one receive antenna (single antenna interference cancellation) are distinguished. Several receive antennas can be also utilized for increasing the robustness against fading, applying diversity combination techniques. In the case of the availability of several transmit antennas only, additional space-time coding has to be used for realization of diversity gains. These aspects are also discussed in depth. Furthermore, an introduction to code-division multiple access (CDMA) transmission is given and it is shown how CDMA is applied in the UMTS system. The lecture is concluded by an introduction to digital transmission in the Long Term Evolution (LTE) system.
6	Learning objectives and skills	The students • describe basic equalization algorithms such as decision-feedback equalization (DFE) and maximum-likelihood sequence estimation (MLSE), • apply equalization algorithms to the GSM / Enhanced Data Rates for GSM Evolution (EDGE) mobile communication system, • formulate channel estimation methods for mobile communication systems, • characterize the interference problem in GSM / EDGE, - design interference suppression schemes for GSM/EDGE for receivers with a single antenna (single antenna interference cancellation) and multiple antennas, respectively, • characterize the performance of mobile communication networks for different reception schemes, • devise receivers for the realization of diversity gains for multiple receive antennas,

		• design space-time coding schemes for the realization of diversity gains for multiple transmit antennas, • describe transmission schemes which are based on code-division multiple access (CDMA), • apply reception techniques for CDMA to the UMTS system, • characterize the uplink transmission in the Long Term Evolution (LTE) system, • develop receivers for LTE. Die Studierenden • beschreiben grundlegende Entzerrverfahren wie entscheidungsrückgekoppelte Entzerrung (Decision-Feedback Equalization, DFE) und Maximum-Likelihood-Sequenzschätzung (Maximum-Likelihood Sequence Estimation, MLSE), • wenden Entzerrverfahren auf das GSM/EDGE (Enhanced Data Rates for GSM Evolution) Mobilfunksystem an, • formulieren Kanalschätzverfahren für Mobilfunksysteme, • charakterisieren das Interferenzproblem bei GSM/EDGE, • entwerfen Interferenzunterdrückungsverfahren für GSM/EDGE für Empfänger mit einer Antenne (Single Antenna Interference Cancellation) und mehreren Antennen, • bewerten die Leistungsfähigkeit von Mobilfunknetzen bei Einsatz verschiedener Empfangsverfahren, • konzipieren Empfänger zur Realisierung von Diversitätsgewinnen bei empfangsseitiger Antennendiversität • entwerfen Space-Time-Codiervverfahren zur Realisierung von Diversitätsgewinnen bei sendeseitiger Antennendiversität, • beschreiben auf Code-Division Multiple Access (CDMA) basierende Übertragungsverfahren, • wenden Empfangsverfahren für CDMA auf das UMTS-System an, • charakterisieren die Aufwärtsstrecke von Long Term Evolution (LTE), • entwerfen Empfänger für LTE.
7	Prerequisites	Systemtheorie, Nachrichtenübertragung
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written or oral Oral exam, 30 minutes.
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h

14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Lecture notes

1	Module name 965820	Approximate Computing Approximate computing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Joachim Falk Prof. Dr.-Ing. Jürgen Teich
5	Contents	Approximate Computing denotes a quite young research area that exploits the fact and capability of many applications and systems to tolerate imprecision and/or inexactness of computed results. Prominent areas of applications and novel techniques of computing approximate rather than exact results have brought up new implementations either at hardware and/or software levels for important emergent workloads such as searching, mining, image processing, and data retrieval. Although hardware technology is improving at a fast pace, energy and power are becoming more and more important constraints apart from exactly computing results in an acceptable amount of time. The main goals of approximate computing techniques are therefore to exploit the possible trade-off between power/energy consumption, accuracy, performance, and/or cost, e.g., utilized hardware resources. The purpose of the course approximate computing is to instruct students about the main ideas and concepts of approximate computing. This includes analyzing the trade-off between energy consumption, accuracy, run-time and hardware costs, concrete approximating techniques (e.g. approximate hardware synthesis, approximating algorithms) as well as theoretical background (determining the computational error and its complexity).
6	Learning objectives and skills	Fachkompetenz - Wissen - The students know the principles and benefits of Approximate Computing and when it is applicable. - The students know multiple error metrics and their semantic meaning. Fachkompetenz - Verstehen - The students understand the difference between the error metrics. - The students understand the principle of function falsification. - The students can apply the presented approximation techniques. Fachkompetenz - Anwenden - The students are capable of choosing the appropriate approximation technique based on given requirements.
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Networking & Collaboration - specialization module Bachelor of Science Autonomy Technologies 20242

		Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable Oral exam in case of less than 20 participants (duration 30 mins). Otherwise, written exam (duration 90 mins).
11	Grading procedure	Variable (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Weitere Informationen: https://www.cs12.tf.fau.de/lehre/lehrveranstaltungen/vorlesungen/approximate-computing

1	Module name 92345	Human-centered mechatronics and robotics	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Philipp Beckerle	
5	Contents	- Human-oriented design methods - Biomechanics Motions, measurement, and analysis Biomechanical models - Elastic actuators - Control methods Cognitive and physical human-robot interaction Empirical research methods - Research process and experiment design - Research methods, interferences, and ethics System integration and fault treatment The exercise will combine simulation sessions and a flip-the-classroom seminar where student groups present recent research papers and discuss them with all attendees.	
6	Learning objectives and skills	On successful completion of this module, students will be able to: - Tackle the interdisciplinary challenges of human-centered robot design. - Use engineering methods for modeling, design, and control to develop human-centered robots. - Apply methods from psychology (perception, experience), biomechanics (motion and human models), and engineering (design methodology) and interpret their results. - Develop robotic systems that are provide user-oriented interaction characteristics in addition to efficient and reliable operation.	
7	Prerequisites	None	
8	Integration in curriculum	semester: 6	
9	Module compatibility	Human-system Interfaces - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242	
10	Method of examination	Written examination (90 minutes)	
11	Grading procedure	Written examination (100%)	
12	Module frequency	Only in summer semester	
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h	

14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• Ott, C. (2008). Cartesian impedance control of redundant and flexible-joint robots. Springer. • Whittle, M. W. (2014). Gait analysis: an introduction. Butterworth-Heinemann. • Burdet, E., Franklin, D. W., & Milner, T. E. (2013). Human robotics: neuromechanics and motor control. MIT press. • Gravetter, F. J., & Forzano, L. A. B. (2018). Research methods for the behavioral sciences. Cengage Learning. • Further topic-specific text books and selected research articles.

1	Module name 92359	Robot mechanisms and user interfaces	5 ECTS
2	Courses / lectures	Vorlesung: Robot mechanisms and user interfaces (2 SWS) Übung: Robot mechanisms and user interfaces (Exercise) (2 SWS) Attendance is not mandatory.	5 ECTS 5 ECTS
3	Lecturers	Rodrigo Jose Velasco Guillen Prof. Dr.-Ing. Philipp Beckerle	

4	Module coordinator	Prof. Dr.-Ing. Philipp Beckerle Mehmet Ege Cansev
5	Contents	Mechanical components, short overview/repetition of machine elements, Robot mechanisms, Kinematic parameters and calculations, Evaluation metrics and design methods, Redundant mechanisms and actuation, Human-robot interfaces, Intend detection (sensing) and haptic stimulation (actuators), Interface system design and evaluation, Mechanical and cognitive user models A flip-the-classroom seminar with student presentations and discussion is part of the lecture. The laboratory exercise will be a mini design project in which student groups create their own low-budget haptic human-machine interfaces.
6	Learning objectives and skills	On successful completion of this module, students will be able to: Understand robot mechanisms and apply kinematic calculations for their design and control, Exploit redundancy in kinematic chains and actuation systems, Know components of human-machine interfaces and be able to design such systematically, Know approaches to model human characteristics and behavior for human-machine interface design.
7	Prerequisites	None
8	Integration in curriculum	semester: 5;6
9	Module compatibility	Human-system Interfaces - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Attendance accounts to 56h and self-study to 94h. It is a written exam that accounts to 100% of the final grade.
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester

15	Teaching and examination language	english
16	Bibliography	Rinderknecht, S. (2018). Einführung in die Mechatronik für den Maschinenbau. Shaker. Lenarcic, J., Bajd, T., & Stanisic, M. M. (2013). Robot mechanisms. Springer. Hatzfeld, C., & Kern, T. A. (2016). Engineering haptic devices. Springer. Selected research articles.

1	Module name 645618	Human Computer Interaction Human computer interaction	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Björn Eskofier Madeleine Flaucher
5	Contents	Das Modul vermittelt Konzepte, Prinzipien, Modelle, Methoden und Techniken für die effektive Entwicklung von benutzerfreundlichen Mensch-Computer-Schnittstellen. Das Thema moderner Benutzungsschnittstellen wird dabei für klassische Computer aber auch für mobile Geräte, eingebettete Systeme, Automobile und intelligente Umgebungen betrachtet. Die folgenden Themen werden im Modul behandelt: • Einführung in die Grundlagen der Mensch-Computer-Interaktion, historische Entwicklung • Entwurfsprinzipien und Modelle für moderne Benutzungsschnittstellen und interaktive Systeme • Informationsverarbeitung des Menschen, Wahrnehmung, Motorik, Eigenschaften und Fähigkeiten des Benutzers • Interaktionskonzepte und -stile, Metaphern, Normen, Regeln und Style Guides • Ein- und Ausgabegeräte, Entwurfsraum für interaktive Systeme • Analyse-, Entwurfs- und Entwicklungsmethoden und -werkzeuge für Benutzungsschnittstellen • Prototypische Realisierung und Implementierung von interaktiven Systemen, Werkzeuge • Architekturen für interaktive Systeme, User Interface Toolkits und Komponenten • Akzeptanz, Evaluationsmethoden und Qualitätssicherung Contents: The module aims to teach basic knowledge of concepts, principles, models, methods and techniques for developing highly user-friendly Human-Computer Interfaces. Beyond traditional computer systems, modern user interfaces are also discussed in the context of automobile and intelligent environments, mobile devices and embedded systems. This module addresses the following topics: • Introduction to the basics of Human-Computer Interaction • Design principles and models for modern user interfaces and interactive systems • Information processing of humans, perception, motor skills, properties and skills of the users • Interaction concepts, metaphors, standards, norms and style guides

		• In- and output devices, design space for interactive systems • Analysis-, design- and development of methodologies and tools for easy-to-use user interfaces • Prototypic implementation of interactive systems • Architectures for interactive systems, User Interface Toolkits and components • Acceptance, evaluation methods and quality assurance
6	Learning objectives and skills	• Studierende entwickeln ein Verständnis für Modelle, Methoden und Konzepte der Mensch-Computer-Interaktion. • Sie lernen verschiedene Ansätze für den Entwurf, die Entwicklung und Bewertung von Benutzungsschnittstellen kennen und verstehen deren Vor- und Nachteile. • Die Teilnahme an der Veranstaltung versetzt Studierende in die Lage, einen Entwicklungsprozess in der Mensch-Computer-Interaktion zu verstehen und umzusetzen. • Sie werden weiterhin in die Lage versetzt, dies vor dem Hintergrund der Informationsverarbeitungsfähigkeit, Wahrnehmung und Motorik des Benutzers zu gestalten. • Passende Methoden der Evaluation sowie Akzeptanz- und Qualitätssicherung werden erlernt. Learning Objectives and Competences: • Students develop an understanding of models, methods and concepts in the field of Human-Computer Interaction. • They learn different approaches for designing, developing and evaluating User Interfaces and their advantages and disadvantages. • Joining the course enables students to understand and execute a development process in Human-Computer Interaction. • Students will be able to do a UI evaluation by learning the basics of information processing, perception and motoric skills of the user. • Appropriate evaluation methods, as well as acceptance and quality assurance aspects, will be learned.
7	Prerequisites	None
8	Integration in curriculum	semester: 5;6
9	Module compatibility	Human-system Interfaces - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Electronic examination Electronic exam (in presence), 90min
11	Grading procedure	Electronic examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h

14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 47616	Intent Detection and Feedback Intent detection and feedback	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Claudio Castellini
5	Contents	• Introduction to the problems of intent detection and somatosensory feedback: motivation, taxonomy, historical background. • Intent detection: theory and philosophical issues; defining the problem and the ground truth; success metrics; signals for intent detection; sensors for intent detection; feature extraction; applications of machine learning to the problem. • Somatosensory feedback: theory and physiology; sensory substitution; embodiment and agency induced by it; modalities of actuation; practical issues and metrics of performance. • Intent detection and somatosensory feedback in prosthetics: usefulness, success and challenges. • Intent detection and somatosensory feedback in rehabilitation and exoskeletons: usefulness, success and challenges. • Intent detection and somatosensory feedback in gaming and non-reha fields.
6	Learning objectives and skills	Students who have followed the module • have a broad understanding of intent detection and somatosensory feedback, especially in the frame of Rehabilitation and Assistive Robotics • can conceive and design a research project in the related subfield of the subject • have knowledge about the clinical and industrial situation of intent detection and feedback, especially including the problems and challenges of each technique and method • can tackle previously unknown problems
7	Prerequisites	Recommended: basic maths, especially statistics; fundamentals of signal processing and machine learning; mid-level programming Python, C# or similar; fundamentals of experimental psychology
8	Integration in curriculum	semester: 5;6
9	Module compatibility	Human-system Interfaces - core modules Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable (60 minutes) Written examination (60 min)
11	Grading procedure	Variable (100%) Written examination (100 %)

12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• [2010] Control of Hand Prostheses Using Peripheral Information, S. Micera, J. Carpaneto and S. Raspopović. • [2012] Control of Upper Limb Prostheses: Terminology and Proportional Myoelectric ControlA Review, A. Fougner, Ø. Stavdahl, P. J. Kyberd, Y. G. Losier and P. A. Parker. • [2015] Michael R Tucker et al., Control strategies for active lower extremity prosthetics and orthotics: a review, JNER 12:1 • [2015] A survey of sensor fusion methods in wearable robotics, D. Novak and R. Riener • [2016] Incremental Learning of Muscle Synergies: From Calibration to Interaction, C. Castellini. • [2018] JA Spanias, AM Simon, SB Finucane, EJ Perreault and LJ Hargrove, Online adaptive neural control of a robotic lower limb prosthesis, J Neural Eng. 15(1) • [2020] Jacob Rosen and Peter Walker Ferguson (eds.), Wearable Robotics Systems and Applications, Academic Press Elsevier • [2021] Michele Xiloyannis, Ryan Alicea, Anna-Maria Georgarakis, Florian L. Haufe, Peter Wolf, Lorenzo Masia and Robert Riener, Soft robotic suits: State of the art, core technologies and open challenges, IEEE Transactions on Robotics

1	Module name 816185	Body Area Communications Body area communications	2,5 ECTS
2	Courses / lectures	Vorlesung: Body Area Communications (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Georg Fischer	

4	Module coordinator	Prof. Dr.-Ing. Georg Fischer
5	Contents	Contents: The Lecture and exercise deals with the following topics: • Introduction to Body Area Communications • Electromagnetic Characteristics of Human Body • Electromagnetic Analysis Methods • Body Area Channel Modeling • Modulation/Demodulation • Body Area Communication Performance • Electromagnetic Compatibility Consideration
6	Learning objectives and skills	Learning objectives • Students understand the challenges in designing Body Area Communication (BAC) systems • Students can conduct basic design decisions with BAC systems, like frequency and modulation selection • Students understand electromagnetic wave propagation in bodies • Students understand the frequency dependent loss and propagation behavior of electromagnetic waves • Students can analyze the communication performance of a BAC system • Students can evaluate Electromagnetic Compatibility of a BAC system • Students can assess the field strength inside body and relate it to regulatory limits like SAR (Specific Absorption rate), frequency dependent maximum electrical and magnetic field strength • Students can sketch block diagrams of BAC systems • Students can derive channel models for BAC
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h

14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 47623	Human-Robot Co-Adaptation Human-robot co-adaptation	5 ECTS
2	Courses / lectures	Vorlesung: Human-Robot Co-Adaptation, Theory - - THIS COURSE IS ONLY ONLINE in WS25! Please follow the links on Studon. (2 SWS) Übung: Human-Robot Co-Adaptation, Exercises - - THIS COURSE IS ONLY ONLINE in WS25! Please follow the links on Studon. (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Dr. rer. nat. Sabine Thürauf Prof. Dr. Claudio Castellini	

4	Module coordinator	Prof. Dr. Franziska Mathis-Ullrich
5	Contents	• Introduction to user studies: designing them; carrying them out; statistical tools to evaluate them • human-robot interaction, with specific focus upon rehabilitation and assistive robotics (prosthetics, exoskeletons, walking aids); • intent detection, somatosensory feedback and sensory substitution; • measurement of relevant changes in the user's behaviour and signals and in the robotic artefact; • co-adaptation and the related clinical perspective.
6	Learning objectives and skills	Students who have followed the course • have a broad understanding of the concept of co-adaptation • can conceive and design an intent-detection + feedback system which will potentially induce co-adaptation • can then analyse the data, both offline and online • can tackle previously unknown problems
7	Prerequisites	Recommended: • basic maths, especially statistics • fundamentals of signal processing and machine learning • mid-level programming (Python, C# or similar) • fundamentals of experimental psychology.
8	Integration in curriculum	semester: 1
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable (120 minutes) Written exam, 120 min.
11	Grading procedure	Variable (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester

15	Teaching and examination language	english
16	Bibliography	• [2015] A survey of sensor fusion methods in wearable robotics, D. Novak and R. Riener • [2016] Incremental Learning of Muscle Synergies: From Calibration to Interaction, C. Castellini. • [2016] New developments in prosthetic arm systems, I. Vujaklija, D. Farina and O.C. Aszmann. • [2017] Hahne, J. M., Markovic, M., & Farina, D. (2017). User adaptation in Myoelectric Man-Machine Interfaces. Scientific Reports, 7. • [2021] Farina, D., et al. (2021). Toward higher-performance bionic limbs for wider clinical use. Nature biomedical engineering.

1	Module name 47617	Rehabilitation and Assistive Robotics Rehabilitation and assistive robotics	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Claudio Castellini
5	Contents	• Introduction to Rehabilitation and Assistive Robotics: motivation, taxonomy, historical background • Prosthetics: upper- and lower limb prosthetics; clinical, mechatronics and societal challenges; machine learning and intent detection applied to prosthetics; signals and sensors. • Exoskeletons and exo-suits: realms of application, mechatronic and ergonomic challenges; intent detection and feedback; clinical acceptance, feasibility and effectiveness.
6	Learning objectives and skills	Students who have followed the module • have a broad understanding of Rehabilitation and Assistive Robotics, the motivations, problems and challenges • can conceive and design a research project in the related subfield of the subject • have knowledge about the clinical and industrial situation in RAR • can tackle previously unknown problems
7	Prerequisites	Recommended: basic maths, especially statistics; fundamentals of signal processing and machine learning; mid-level programming (Python, C# or similar); fundamentals of experimental psychology
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable (60 minutes) Written examination (60 min)
11	Grading procedure	Variable (100%) Written examination (100 %)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• [2002] Control of Multifunctional Prosthetic Hands by Processing the Electromyographic Signal, M. Zecca, S. Micera, M. C. Carrozza and P. Dario.

		• [2010] Control of Hand Prostheses Using Peripheral Information, S. Micera, J. Carpaneto and S. Raspopović. • [2012] Control of Upper Limb Prostheses: Terminology and Proportional Myoelectric ControlA Review, A. Fougner, Ø. Stavadahl, P. J. Kyberd, Y. G. Losier and P. A. Parker. • [2015] Michael R Tucker et al., Control strategies for active lower extremity prosthetics and orthotics: a review, JNER 12:1 • [2018] JA Spanias, AM Simon, SB Finucane, EJ Perreault and LJ Hargrove, Online adaptive neural control of a robotic lower limb prosthesis, J Neural Eng. 15(1) • [2020] Jacob Rosen and Peter Walker Ferguson (eds.), Wearable Robotics - Systems and Applications, Academic Press Elsevier • [2021] Michele Xiloyannis, Ryan Alicea, Anna-Maria Georgarakis, Florian L. Haufe, Peter Wolf, Lorenzo Masia and Robert Riener, Soft robotic suits: State of the art, core technologies and open challenges, IEEE Transactions on Robotics

1	Module name 93101	AI in medical robotics	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: AI in Medical Robotics (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Franziska Mathis-Ullrich Dr.-Ing. Christian-Peter Kunz	

4	Module coordinator	Prof. Dr. Franziska Mathis-Ullrich
5	Contents	This module is concerned with artificial intelligence technologies in medical robotics and with methods that establish different forms of intelligence in medical robotic systems. Participants will become familiar with the design and application of AI methods and algorithms for perception, motor control, planning, cognition and learning and with their application in biorobotic systems and robotic solutions for diagnosis and treatment. Application domains include minimally invasive surgery, motor rehabilitation, exoskeletons and assistive devices, as well as medical service robotics. The taught methods will be applied to application data during designated computer exercises that are integrated into the course. Topics include, but are not limited to: • Basic principles and classification of artificial intelligence • Overview of AI methods and technologies in medical imaging • Implications of surgical workflow planning using AI methods • Motion planning in robotic surgery, rehabilitation robots and medical service robots • Perception in robotic surgery, rehabilitation robots and assistive robots • Motion planning in robotic surgery, rehabilitation robots and assistive robots • Adaptation and Learning in Human-Robot Interaction • Design criteria and regulations for AI-based medical systems
6	Learning objectives and skills	• Students are able to employ artificial intelligence technologies and methods for applications in medical robotics. • They are capable of understanding and handling the complexity of biorobotic AI systems and have command of a versatile set of methods for analyzing and further advancing such systems. • They are able to combine different tools and methods to achieve intelligent perception, planning, control, learning and cognition in robotic solutions for minimally invasive surgery, motor rehabilitation robotics, and medical service robotics.
7	Prerequisites	Participants should be familiar with fundamentals of linear algebra. It is advantageous but not required to have some prior knowledge on robotics, basic methodologies of AI, and basic probability theory.
8	Integration in curriculum	semester: 1
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242

		Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination Written examination (60 min)
11	Grading procedure	Written examination (100%) Written examination (100 %)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 42800	Advanced Topics in Deep Learning Advanced topics in deep learning	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis
5	Contents	The students will learn advanced deep learning topics, including recent network architectures, generative models, self-supervision, interpretability and explainability. In the exercises, the students will implement advanced models and techniques for classification or regression tasks. The lecture topics include: • Geometric deep learning • Attention and transformers • Unsupervised and self-supervised learning • Generative models • Interpretability • Explainability • Efficient Inference • Uncertainty estimation • Transfer learning and domain adaptation • Few-shot learning
6	Learning objectives and skills	The students will learn: • State-of-the-art topics in Deep Learning • Recent Neural network architectures • Generative modelling • Lifelong learning approaches • Robustness and reliability in Deep Learning.
7	Prerequisites	Basic knowledge of machine learning, deep learning, and programming.
8	Integration in curriculum	semester: 1
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Written exam of 90 min duration Schriftliche Prüfung von 90 min Dauer
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h

14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning. • Deisenroth, M. P., Faisal, A. A., & Ong, C. S. (2020). Mathematics for machine learning. Cambridge University Press. • Molnar, C. (2020). Interpretable machine learning. Lulu. com.

1	Module name 42801	Perception in Robotics Perception in robotics	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis
5	Contents	The students will learn robotic perception topics, including camera models, filtering, transformations, low-level features, point-cloud processing, recognition, pose estimation, localization, mapping, depth, and motion estimation. In the exercises, the students will implement techniques for different perception modules. The lecture topics include: • Sensor models • Camera calibration • Feature detection and matching. • Edges, lines, circles. • Transformations. • Multiple views. • Recognition. • Pose estimation. • Localization and mapping. • Depth estimation. • Point-cloud processing.
6	Learning objectives and skills	no learning objectives and skills description available!
7	Prerequisites	Basic knowledge of image and signal processing
8	Integration in curriculum	semester: 1
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (90 minutes) Written examination of 90 min duration <i>Schriftliche Prüfung von 90 min Dauer.</i>
11	Grading procedure	Written examination (100%) A grade bonus of 0.3 is awarded for regular participation in the exercise assignments. The grade bonus can only be counted towards the overall grade only if the examination is passed. A grade improvement from 5.0 to 4.0 is not possible.

12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• Szeliski, Richard. Computer vision: algorithms and applications. Springer Nature, 2022. • Thrun, Sebastian, Wolfram Burgard, and Dieter Fox. "Probalistic robotics.", MIT Press. • Hartley, Richard, and Andrew Zisserman. Multiple view geometry in computer vision. Cambridge University Press, 2003

1	Module name 47708	Robotics in Surgery and Diagnostics Robotics in surgery and diagnostics	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Franziska Mathis-Ullrich
5	Contents	To provide motivation, the various scenarios of robot use in the surgical environment are explained and classified using examples. The fundamentals of robotics are addressed, including different kinematic forms, and key parameters such as degrees of freedom, kinematic chains, workspace, and payload are introduced. This includes the presentation of medically used robots in different size scales, ranging from micro- and nanorobotics to minimally invasive continuum robotics and larger systems for robot-assisted surgery. Next, the different modules of the process chain for robot-assisted surgery are presented. It begins with medical imaging and the various tomographic techniques, explaining their physical principles and their diagnostic information about anatomy and pathology. Medical image processing, with a focus on segmentation, follows. This leads to the geometric 3D reconstruction of anatomical structures, forming the basis for an attributed patient model. The methods for registering preprocessed measurement data from different tomographic modalities are described. The various approaches for modeling tissue parameters complement the discussions, forming a complete patient model. The applications of the patient model in visualization and surgical planning are the next topic. The intraoperative part of the process chain includes registration, navigation, augmented reality, and surgical robotic systems. These are explained with fundamentals and application examples. Key points here include techniques for robot-assisted tissue cutting and approaches to micro- and nanosurgery. Finally, applications of machine learning in medical robotics are discussed. The lecture concludes with a brief discourse on specific safety issues and the legal aspects of medical products.
6	Learning objectives and skills	Students • have a good overview of existing surgical and medical robotic systems in research and practical applications. • understand the specific requirements of surgery for automation with robots. • can recognize basic kinematics and their relevance to medical requirements and applications. • are familiar with basic techniques for processing and using image data from different modalities and can apply them. • can design the complete workflow for a robot-assisted procedure.

7	Prerequisites	Recommended by the lecturer(s): Knowledge on robotics design, robot kinematics
8	Integration in curriculum	semester: 1
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable Written examination; duration 60 minutes
11	Grading procedure	Variable (100%) Written examination 100%
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 96837	A look inside the human body - gait analysis and simulation	2,5 ECTS
2	Courses / lectures	Vorlesung: A look inside the human body - gait analysis and simulation (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Anne Koelewijn	

4	Module coordinator	Prof. Dr. Anne Koelewijn
5	Contents	The aim of this lecture is to teach methods of gait analysis and simulation. Gait analysis experiments will be covered, as well as more modern approaches to gather walking data. Techniques to process gait analysis experiments are discussed, as well as dynamic models that can be used to create gait simulations. This lecture addresses the following topics: • Measurement systems for gait analysis • Methods to calculate joint kinetics and kinematics from experimental data • Muscle biology, specific to force generation, and modelling of muscles • Methods to calculate muscle activation from experimental data • Energetics of walking • Multibody dynamics • Creating simulations of gait
6	Learning objectives and skills	Learning objectives: • Be familiar with the existing measurement options for gait analysis • Know state-of-the art techniques to process gait analysis experiments • Select an appropriate processing technique for a specific experiment • Understand how gait could be simulated and where these simulations could be applied • Know the function of the different components of the human body that are involved in locomotion
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable
11	Grading procedure	Variable (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english

16	Bibliography	• Winter, David A. Biomechanics and motor control of human movement. John Wiley & Sons, 2009. • Kelly, Matthew. "An introduction to trajectory optimization: How to do your own direct collocation." SIAM Review 59.4 (2017): 849-904.

1	Module name 47575	Gait analysis and simulation+	5 ECTS
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	Module coordinator	Prof. Dr. Anne Koelewijn
5	Contents	The aim of this course is to teach methods of gait analysis and simulation. The lectures start with an introduction to relevant anatomic terms and definitions, followed by an introduction to the motions performed when walking or running. Different sensors and laboratory equipment are introduced, which are used to record gait/human movement. We will discuss different processing methods that can be used to determine relevant kinetic and kinematic parameters related to gait, such as joint angles, joint moments, and muscle forces. The second half of the lectures will focus on gait simulations. First, we discuss simulation methods, dynamic models and optimization techniques used to create gait simulations. Second, neural control of gait is discussed, as well as how simulations can be created to investigate this neural control. This lecture addresses the following topics: • Measurement systems for gait analysis • Methods to calculate joint kinetics and kinematics from experimental data • Muscle biology specific to force generation, and modelling of muscles • Methods to calculate muscle activation and force from experimental data • Energetics of walking • Multibody dynamics • Trajectory optimization for gait simulations Gait simulations based on neural control models
6	Learning objectives and skills	Knowledge: • The students learn what a normal walking and running gait cycle looks like • The students learn about the human body and commonly used anatomical and engineering terms that are important to describe locomotion. • The students learn about commonly used measurement and processing techniques to measure and calculate biomechanical parameters related to gait • The students learn how human gait simulations can be created. • The students learn about the control of human gait. Understanding: • The students understand the advantages and disadvantages of different data processing methods, models, and gait simulation methods.

		- The students understand when a simulation and when an experiment is appropriate to answer a research question Application - The students are able to develop an approach to answer a research question related to gait - The students are able to perform a gait analysis experiment and process with state-of-the-art methods - The students are able to implement numerical simulation methods in MATLAB or Python - The students are able to use the open source software OpenSim and SCONE Analyse - The students are able to analyse gait kinetics and kinematics and identify abnormalities
7	Prerequisites	No compulsory prerequisites. Background knowledge on multibody dynamics, simulation, and optimization is recommended
8	Integration in curriculum	semester: 1
9	Module compatibility	Planning & Control - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Tutorial achievement Variable Written examination
11	Grading procedure	Tutorial achievement (pass/fail) Variable (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	?? semester (no information for Module duration available)
15	Teaching and examination language	
16	Bibliography	

1	Module name 93074	Introduction to Cybersecurity Fundamentals in Networking	5 ECTS
2	Courses / lectures	Vorlesung: Introduction to Cybersecurity Fundamentals in Networking (2 SWS, WiSe 2025) Übung: Introduction to Cybersecurity Fundamentals in Networking Exercises (2 SWS, WiSe 2025)	2,5 ECTS 2,5 ECTS
3	Lecturers	Loui Al Sardy	

4	Module coordinator	Loui Al Sardy Prof. Dr. Reinhard German
5	Contents	In today's interconnected world, cybersecurity plays a critical role in safeguarding sensitive information and ensuring the integrity, confidentiality, and availability of digital assets. The "Introduction to Cybersecurity Fundamentals in Networking" course provides students with a comprehensive understanding of the foundational principles, concepts, and practices of cybersecurity within the context of networking environments. Through a combination of theoretical lectures, hands-on lab exercises, and real-world case studies, students will explore key topics including security principles, risk management, access controls, cryptography, network security protocols, and emerging technologies. The course also covers the importance of cybersecurity for businesses and individuals, emphasizing the identification and mitigation of common security threats, vulnerabilities, and attack vectors. Additionally, students will learn about compliance with industry standards and regulations, such as GDPR and HIPAA, and explore emerging trends in network security, including blockchain and IoT. By the end of the course, students will have developed a solid foundation in cybersecurity fundamentals, equipped with the knowledge, skills, and competencies needed to address the evolving challenges of cybersecurity in today's digital landscape.
6	Learning objectives and skills	• Understand core cybersecurity principles and their significance for businesses. • Identify and mitigate common network threats and vulnerabilities. • Develop skills in securing network devices, implementing access controls, enforcing security policies, and best practices. • Knowledge of fundamental principles and concepts of cybersecurity. • Knowledge of cryptographic techniques and various network security protocols. • Gain practical experience through hands-on lab exercises and case studies.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242

10	Method of examination	Variable 90-minute final exam or 30-minute oral exam on the content of the lecture and exercises, depending on the number of participants (will be announced at the start of the semester).
11	Grading procedure	Variable (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: approx. 60 h Independent study: approx. 90 h
14	Module duration	1 Semester semester
15	Teaching and examination language	english
16	Bibliography	• "Computer Security: Principles and Practice" by William Stallings and Lawrie Brown • "Cybersecurity for Beginners" by Raef Meeuwisse • "Network Security Essentials" by William Stallings • "Introduction to Computer Security" by Michael Goodrich and Roberto Tamassia • "Cryptography and Network Security: Principles and Practice" by William Stallings • "Network Security Bible" by Eric Cole and Ronald Krutz

1	Module name 47664	Fundamentals in Anatomy and Physiology for Engineers Fundamentals in anatomy and physiology for engineers	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers. For more information, please join the StudOn course.	
3	Lecturers	-	

4	Module coordinator	apl. Prof. Dr. Michael Eichhorn
5	Contents	• Biological Systems • Trunk System • Nervous System • Respiration • Circulation • Heart • Digestion • Neuroscience • Functional cardiology • Advanced endoscopy • Advanced neuroimaging
6	Learning objectives and skills	Students are able to • describe relevant structures of the human anatomy and basic physiological processes • understand features of biological systems when applying optical technologies to them • describe exemplarily applications of optical technologies in medicine
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242 Written exam (on-site), 60 min.
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Gerard J. Tortora, Bryan Derrickson: Principles of Anatomy and Physiology:

1	Module name 44455	Speech and Language Processing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Andreas Maier
5	Contents	Nach Behandlung der grundlegenden Mechanismen menschlicher Spracherzeugung und Sprachwahrnehmung gibt die Vorlesung eine detaillierte Einführung in (vornehmlich) statistisch orientierte Methoden der maschinellen Erkennung gesprochener Sprache. Schwerpunktthemen sind Merkmalsgewinnung, Vektorquantisierung, akustische Sprachmodellierung mit Hilfe von Markovmodellen, linguistische Sprachmodellierung mit Hilfe stochastischer Grammatiken, prosodische Information sowie Suchalgorithmen zur Beschleunigung des Dekodiervorgangs. After focussing on of the basic mechanisms of human speech generation and speech perception the lecture gives a detailed introduction to (mainly) statistically oriented methods of automatic recognition of spoken language. Main topics are feature extraction, vector quantization, acoustic speech modeling with the help of Markov models, linguistic speech modeling with the help of stochastic grammars, prosodic information as well as search algorithms to speed up the decoding process.
6	Learning objectives and skills	Die Studierenden • verstehen die Grundlagen der menschlichen Sprachproduktion und die akustischen Eigenschaften unterschiedlicher Phonemklassen • erklären den allgemeinen Aufbau eines Mustererkennungssystems • verstehen Abtastung, das Abtasttheorem und Quantisierung in Bezug auf Sprachsignale • verstehen die Fourier-Transformation und mathematische Modelle der Sprachproduktion • verstehen harte und weiche Vektorquantisierungsmethoden • verstehen unüberwachtes Lernen (EM-Algorithmus) • verstehen Hidden Markov-Modelle (HMMs) • erklären stochastische Sprachmodelle The students • understand the principles of human speech production and acoustic properties of the different phoneme classes • explain the general pipeline of a pattern recognition system • understand sampling, the sampling theorem, and quantization w.r.t. speech signals

		• understand Fourier transformation and mathematical models of speech production • understand hard and soft vector quantization methods • understand unsupervised learning (EM-algorithm) • understand Hidden Markov Models (HMMs) • explain stochastic language models
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (60 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	• Niemann H.: Klassifikation von Mustern; Springer, Berlin 1983 • Niemann H.: Pattern Analysis and Understanding; Springer, Berlin 1990 • Schukat-Talamazzini E.G.: Automatische Spracherkennung; Vieweg, Wiesbaden 1995 • Rabiner L.R., Juang B.H.: Fundamentals of Speech Recognition; Prentice Hall, New Jersey 1993

1	Module name 44159	Surgical Technologies Innovation	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Franziska Mathis-Ullrich
5	Contents	The module involves theoretical and practical course work. Interactive lectures will provide introduction to medical technologies, surgical robotics and machine learning for surgical applications. In addition, through lectures, experts from several surgical disciplines (e.g. Neurosurgery, Abdominal surgery, Urology, Orthopedic surgery) will introduce their surgical fields and point out current challenges in their respective fields. During hospitalizations at the operation room, students gain understanding about surgeries and are to identify problems and worksteps that may be solved and/or supported by novel medical technologies. In exercise teams, the students will research and develop technologies to support surgeons in the respective surgical discipline and evaluate them in the lab. If successful, students are encouraged to submit and present their work at a medical technologies conference.
6	Learning objectives and skills	Students • are able to identify challenges in surgical procedures through observation and interviews • are able to solve a practical problem from the field of medical technology independently. • are able to specify and implement hardware and software required to solve a given problem. • apply basic knowledge to a problem and develop solution strategies. • are able to solve a problem alone or as part of a team. • have knowledge of the phases of a project, time, and resource management. • are confident in the use of software development tools, source code management, and documentation. • are able to convey complex technical content in a scientific report and presentation.
7	Prerequisites	• ◦ AI in Medical Engineering, ◦ Robotics in Surgery and Diagnostics, ◦ Empirical Research Methods in Medical Engineering • ◦ AI, ◦ robotics ◦ surgical application will be an advantage. • A high degree of motivation and independency is expected.

		The number of accepted students is limited.
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Human-system Interfaces - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable Written report and presentation; attendance at exercises is mandatory
11	Grading procedure	Variable (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
14	Module duration	1 semester
15	Teaching and examination language	german or english
16	Bibliography	

1	Module name 47595	Seminar The why and how of human gait simulations Seminar: The why and how of human gait simulations	5 ECTS
2	Courses / lectures	Seminar: The why and how of human gait simulations (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Anne Koelewijn	

4	Module coordinator	Prof. Dr. Anne Koelewijn
5	Contents	In this module, students will analyse, present and discuss issues and topics concerning the usage of biological signals in rehabilitation and assistive robotics, including the correct placement and use of the associated sensors, the techniques to condition the signals, sensor fusion, feature extraction and the usage of machine learning applied to such kind of signals. Besides reflecting on contemporary literature, the students are asked to draw own conclusions and suggest directions for future research.
6	Learning objectives and skills	On successful completion of the module, students will be familiar with sensors and signals used in rehabilitation and assistive robotics, both theoretically and practically. They will also be able to deduce potential new research lines from recent developments.
7	Prerequisites	Recommended: basic maths, especially statistics; fundamentals of signal processing and machine learning.
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Human-system Interfaces - Seminar & Laboratory Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Seminar achievement
11	Grading procedure	Seminar achievement (100%)
12	Module frequency	no Module frequency information available!
13	Workload in clock hours	Contact hours: 30 h Independent study: 120 h
14	Module duration	1 semester
15	Teaching and examination language	
16	Bibliography	• [2002] Control of Multifunctional Prosthetic Hands by Processing the Electromyographic Signal, M. Zecca, S. Micera, M. C. Carrozza and P. Dario. • [2010] Control of Hand Prostheses Using Peripheral Information, S. Micera, J. Carpaneto and S. Raspopović. • [2015] A survey of sensor fusion methods in wearable robotics, D. Novak and R. Riener

1	Module name 267499	Linear and non-linear fibre optics	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Bernhard Schmauß	
5	Contents	Optical data transmission systems are the enabler for our modern communication networks. Since the first systems have been installed, the transmission capacity as well as the transmission distance has been increased dramatically. The migration from point-to-point transmission systems to complex optical networks is still in progress. The fast evolution of optical transmission technology is stimulated by innovations in the field of the system key components. The lectures concentrate on the physical effects and properties of key components like semiconductor lasers, optical modulators, optical fibers, optical amplifiers and detector diodes. Especially also the nonlinear effects of the transmission fiber are discussed. The main focus is on the effects and characteristics which are important to achieve a certain system performance. The influence of component parameters on system performance is presented in examples related to installed systems and systems that are actually in development. The exercises partly use a numerical simulation tool to analyze the component influence on system performance.	
6	Learning objectives and skills	Students • Understand structure and operation of components of optical communication systems • Rate the optical properties of components and evaluate the influence of operational parameters on system performance • Are able to analyze the influence of linear and nonlinear fiber effects on optical signals and system performance • Can make use of system simulation tools to engineer optical links	
7	Prerequisites	Recommended prior knowledge: • Semiconductor physics • Ray optics • Photonics	
8	Integration in curriculum	semester: 1	
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242	
10	Method of examination	Oral (30 minutes)	
11	Grading procedure	Oral (100%)	
12	Module frequency	Only in summer semester	

13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Agrawal, G.P.: Fiber Optic Communication Systems, Willey, New York, 1992 Kaminow, I, Li, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002 Kaminow, I, Li, T., Willner, A.: Optical Fiber Telecommunications VA, Academic Press, 2008

1	Module name 713618	Computer vision	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Tim Weyrich
5	Contents	This lecture discusses important algorithms from the field of computer vision. The emphasis lies on 3-D vision algorithms, covering the geometric foundations of computer vision, and central algorithms such as stereo vision, structure from motion, optical flow, and 3-D multiview reconstruction. Participants of this advanced course are expected to bring experience from prior lectures either from the field of pattern recognition or from the field of computer graphics.
6	Learning objectives and skills	Die Vorlesung stellt eine Auswahl von Methoden aus dem Gebiet der Computer Vision vor, die in dem Feld eine zentrale Stellung einnehmen. In den Übungen implementieren und evaluieren die Studierenden selbständig diese Methoden. Die Studierenden arbeiten die ganze Zeit über an populären Computer Vision-Methoden wie zum Beispiel Stereosehen, optischer Fluss und 3D-Rekonstruktion aus mehreren Ansichten. Für diese Probleme • beschreiben die Studierenden perspektivische Projektion, Rotationen und verwandte geometrische Grundlagen, • erklären die Studierenden die behandelten Methoden, • diskutieren die Studierenden Vor- und Nachteile verschiedener Modalitäten zur Erfassung von 3D-Informationen, • implementieren die Studierenden einzeln und gemeinschaftlich in Kleingruppen Code, • entdecken die Studierenden optimale Vorgehensweisen in der Datenaufnahme, • erkunden und bewerten die Studierenden unterschiedliche Möglichkeiten für die Evaluation, • diskutieren und präsentieren die Gruppenarbeiter in Gruppen die Vor- und Nachteile ihrer Implementierungen, • diskutieren und reflektieren die Studierenden gesellschaftliche Auswirkungen von Anwendungen des 3D-Rechnersehens. The lecture introduces computer vision algorithms that are central to the field. In the exercises, participants autonomously implement and evaluate these algorithms. The participants work throughout the time on popular computer vision algorithms, like for example stereo vision, optical flow, and 3-D multiview reconstruction. For these problems, the participants • describe perspective projection, rotations, and related geometric foundations, • explain the presented methods, • discuss the advantages and disadvantages of different modalities for acquiring 3-D information,

		• implement individually and in small groups code, • discover best practices in data acquisition, • explore and rank different choices for evaluation, • discuss and present in groups the advantages and disadvantages of their implementations, • discuss and reflect the social impact of applications of computer vision algorithms.
7	Prerequisites	None
8	Integration in curriculum	no Integration in curriculum available!
9	Module compatibility	Sensing & Perception - specialization module Bachelor of Science Autonomy Technologies 20242 Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Variable (90 minutes) Dieses Modul wird mit einer Klausur (90 Minuten) geprüft. The form of examination is a written exam of 90 minutes.
11	Grading procedure	Variable (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Richard Szeliski: "Computer Vision: Algorithms and Applications", Springer 2011.

1	Module name 172338	Security in Embedded Hardware Security in embedded hardware	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Joachim Falk Prof. Dr.-Ing. Jürgen Teich
5	Contents	Der Schutz eingebetteter Systeme gegenüber Angriffe Dritter auf gespeicherte Daten und Implementierungen, stellt eine immer wichtigere, jedoch auch durch zunehmende Vernetzung herausfordernde Aufgabe dar. Der Schutz der eingebetteten Systeme gegenüber bekannten als auch neueren ausgeklügelten Angriffsmöglichkeiten ist Gegenstand dieser Vorlesung. Es wird gezeigt, welche Angriffe existieren, welche Gegenmaßnahmen man ergreifen kann und wie man sichere eingebettete Systeme entwirft. Einleitung und Motivation • Was ist Security? • Die Bedeutung von Security für zuverlässige Systeme • Klassifikation von Angriffen • Entwurf eingebetteter Systeme Angriffsszenarien • Beispiele von Angriffsszenarien • Kryptographischer Algorithmen als Ziel von Angriffen Angriffe durch Einschleusen von Code (Code Injection Attacks) • Welche Arten von Code Injection-Angriffe gibt es? • Gegenmaßnahmen Invasive physikalische Angriffe (Invasive Physical Attacks) • Microprobing • Reverse Engineering • Differential Fault Analysis • Gegenmaßnahmen Nichtinvasive softwarebasierte Angriffe (Non-Invasive Logical Attacks) • Erlangen von nicht autorisiertem Zugriff • Gegenmaßnahmen Nichtinvasive physikalische Angriffe (Non-Invasive Physical Attacks) • Abhören • Seitenkanalangriffe • Gegenmaßnahmen
6	Learning objectives and skills	Fachkompetenz - Wissen • Die Studierenden legen die entsprechenden Gegenmaßnahmen dar • Die Studierenden nennen verschiedene Sicherheitseinrichtungen und -maßnahmen in eingebetteten Systemen Fachkompetenz - Verstehen

		- Die Studierenden zeigen den Einfluss von Angriffen und deren Gegenmaßnahmen auf die Verlässlichkeit eines eingebetteten Systems auf - Die Studierenden zeigen den zusätzlichen Aufwand (Fläche, Rechenzeit) von Sicherheitseinrichtungen auf Fachkompetenz - Analysieren - Die Studierenden klassifizieren verschiedene Angriffstypen auf eingebettete Systeme Sozialkompetenz - Die Studierenden erarbeiten kooperativ in Gruppen Lösungskonzepte und implementieren diese gemeinsam
7	Prerequisites	None
8	Integration in curriculum	semester: 1
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Written examination (60 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Empfohlene Bücher zur Begleitung und Vertiefung: - Catherine H. Gebotys Security in Embedded Devices. Springer 2010. - Benoit Badrignans et al. Security Trends for FPGAs. Springer 2011. - Daniel Ziener Techniques for Increasing Security and Reliability of IP Cores Embedded in FPGA and ASIC Designs. Dr. Hut 2010. Weitere Informationen: https://www.cs12.tf.fau.de/lehre/lehrveranstaltungen/vorlesungen/security-in-embedded-hardware

1	Module name 92736	Localization Systems for IoT	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Jörg Robert
5	Contents	Overview of localisation systems for the IoT sector • RSSI-based localisation methods • AoA-based localisation methods • TDoA/ToA-based localisation methods • Implementation in current transmission standards • Algorithms for data evaluation
6	Learning objectives and skills	1) The students understand the functioning of localisation methods in the field of IoT 2) The students analyse the performance and limitations of various localisation methods
7	Prerequisites	Vorlesung Nachrichtentechnische Systeme, Kommunikationselektronik (empfohlen)
8	Integration in curriculum	semester: 1
9	Module compatibility	Technical elective module Bachelor of Science Autonomy Technologies 20242
10	Method of examination	Oral (30 minutes) Tutorial achievement
11	Grading procedure	Oral (100%) Tutorial achievement (pass/fail)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	german
16	Bibliography	Vorlesungsunterlagen