Friedrich-Alexander-Universität
Erlangen-Nürnberg

Module description

for the degree programme

Master of Science
Autonomy Technologies

(Version of examination regulation: 20232)

for the winter term 2026/2027

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1	**Module name** 1999	**Master thesis (M.Sc. Autonomy Technologies 20232)** Master's thesis	**30 ECTS**
2	Courses / lectures	No courses / lectures available for this module for this semester!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module for this semester!	

4	**Module coordinator**	
5	**Contents**	The Master’s thesis is intended to demonstrate the students’ ability to solve problems in Autonomy Technologies independently.
6	**Learning objectives and skills**	Students • acquire the ability to pursue a scientific question over a longer period of time, • work on the relevant subject area independently and within a specified period of time • develop independent ideas and concepts for solving scientific problems • deal in depth and critically with theories, terminology, special features, limits and opinions of the subject • deal with and reflect on the doctrines of the subject area • are able to apply suitable scientific methods largely independently • and develop them further - also in new and unfamiliar as well as interdisciplinary contexts • and present the results in a scientifically appropriate form • can present subject-related content clearly and appropriately for the target group in writing (and orally if necessary) and argue their case • expand their planning and structuring skills in the implementation of a thematic project
7	**Prerequisites**	In order to qualify for admission to the Master’s thesis, students shall be required to successfully complete modules worth at least 80 ECTS credits.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Pflichtmodul Master of Science Autonomy Technologies 20232
10	**Method of examination**	Written (6 Monate) Oral (30 minutes) • The Master's thesis must be set in such a way that it can be completed within six months with a completion time of approx. 900 hours. • The Master’s thesis module includes a report (60-100 pages) and an oral presentation (approximately 30 minutes).
11	**Grading procedure**	Written (90%) Oral (10%) Report (90%)

		Presentation (10%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? semester (no information for Module duration available)
16	**Teaching and examination language**	
17	**Bibliography**	

1	**Module name** 1996	**Team project or Industriepraktikum**	**10 ECTS**
2	Courses / lectures	No courses / lectures available for this module for this semester!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module for this semester!	

4	**Module coordinator**	Prof. Dr.-Ing. Philipp Beckerle Dr.-Ing. Markus Jonscher
5	**Contents**	The team project comprises (some of) the following aspects to be tackled in a team of 4-5 students: Research and development of autonomous systems and their components Requirement analysis Modeling, simulation, and optimization Experimental evaluation Accordingly, not only technical but also management and soft skills are to be explored and to be acquired.
6	**Learning objectives and skills**	Students learn to apply the knowledge acquired during their Autonomy Technology studies to real-world engineering challenges. They systematically identify solutions to implement components and/or systems and optimize them. Moreover, they learn to act as a team, manage joint development processes, and practice to present, critically discuss, and document their results.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Pflichtmodul Master of Science Autonomy Technologies 20232
10	**Method of examination**	Practical achievement Course achievement Course achievement 10-page report and 30 minutes presentation (team work). Passed / Not passed (no grading required). The result and the title of the project need to be provided to the examination office.
11	**Grading procedure**	Practical achievement (pass/fail) Course achievement (pass/fail) Course achievement (pass/fail)
12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 250 h Independent study: 50 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english

16	**Bibliography**	

Human-system interfaces - Core modules

1	**Module name** 92345	**Human-centered mechatronics and robotics**	**5 ECTS**
2	Courses / lectures	Vorlesung: Human-centered mechatronics and robotics (2 SWS) (SoSe 2026) Übung: Human-centered mechatronics and robotics (UE) (2 SWS) (SoSe 2026) Tutorium: Human-centered mechatronics and robotics (Tut) (SoSe 2026)	5 ECTS - -
3	Lecturers	Prof. Dr.-Ing. Philipp Beckerle Maria Luna Ghanime Dr. Léa Boillereaux Rodrigo Jose Velasco Guillen	

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: 1
9	**Module compatibility**	Human-system Interfaces - core modules Master of Science Autonomy Technologies 20232
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	Prof. Dr.-Ing. Philipp Beckerle Rodrigo Jose Velasco Guillen	

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: 1
9	**Module compatibility**	Human-system Interfaces - core modules Master of Science Autonomy Technologies 20232
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	Übung: Human Computer Interaction Exercises (1 SWS) (SoSe 2026) Vorlesung: Human Computer Interaction (3 SWS) (SoSe 2026)	1,25 ECTS 3,75 ECTS
3	Lecturers	Alexander Weiß Prof. Dr.-Ing. Philipp Beckerle Rodrigo Jose Velasco Guillen	

4	**Module coordinator**	Prof. Dr. Björn Eskofier
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: 1
9	**Module compatibility**	Human-system Interfaces - core modules Master of Science Autonomy Technologies 20232
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	Vorlesung: Intent Detection and Feedback, Theory (2 SWS) (SoSe 2026) Übung: Intent Detection and Feedback, Exercises (2 SWS) (SoSe 2026)	2,5 ECTS 2,5 ECTS
3	Lecturers	Fabio Egle Prof. Dr. Claudio Castellini	

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: 1
9	**Module compatibility**	Human-system Interfaces - core modules Master of Science Autonomy Technologies 20232
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	Vorlesung: Image and Video Compression (IVC) (4 SWS) (SoSe 2026) Übung: Übung zu Image and Video Compression (SoSe 2026)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Andre Kaup Anna Meyer	

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: 1
9	**Module compatibility**	Human-system Interfaces - specialization module Master of Science Autonomy Technologies 20232 Networking & Collaboration - specialization module Master of Science Autonomy Technologies 20232 Sensing & Perception - specialization module Master of Science Autonomy Technologies 20232
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: 1
9	**Module compatibility**	Human-system Interfaces - specialization module Master of Science Autonomy Technologies 20232 Sensing & Perception - core modules Master of Science Autonomy Technologies 20232
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	Dr. Alexander Popugaev	

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**	semester: 1
9	**Module compatibility**	Human-system Interfaces - specialization module Master of Science Autonomy Technologies 20232
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 (2 SWS) Übung: Human-Robot Co-Adaptation, Exercises (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr. Claudio Castellini Fabio Egle	

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 Master of Science Autonomy Technologies 20232
10	**Method of examination**	Variable (60 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	Vorlesung: Rehabilitation and Assistive Robotics, Theory (2 SWS) (SoSe 2026) Übung: Rehabilitation and Assistive Robotics, Exercises (2 SWS) (SoSe 2026)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr. Claudio Castellini Dr. rer. nat. Sabine Thürauf	

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**	semester: 1
9	**Module compatibility**	Human-system Interfaces - specialization module Master of Science Autonomy Technologies 20232
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 Control: A 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 • [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 be 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 Master of Science Autonomy Technologies 20232

10	**Method of examination**	Written examination (90 minutes) 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	Vorlesung mit Übung: Robotics in Surgery and Diagnostics (4 SWS) (SoSe 2026)	5 ECTS
3	Lecturers	Prof. Dr. Franziska Mathis-Ullrich Steffen Peikert	

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 Master of Science Autonomy Technologies 20232
10	**Method of examination**	Variable (90 minutes) 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	Vorlesung mit Übung: Surgical Technologies Innovation	-
3	Lecturers	Jasmin Arjomandi Prof. Dr. Franziska Mathis-Ullrich Dr.-Ing. Christian-Peter Kunz	

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 hospitations 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**	• o AI in Medical Engineering, o Robotics in Surgery and Diagnostics, o Empirical Research Methods in Medical Engineering • o AI, o robotics o 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 Master of Science Autonomy Technologies 20232
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** 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**	Human-system Interfaces - specialization module Master of Science Autonomy Technologies 20232
10	**Method of examination**	Variable Variable Written exam, 60 min.
11	**Grading procedure**	Variable (100%) 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.

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 Alireza Navi	

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: 1
9	**Module compatibility**	Networking & Collaboration - core modules Master of Science Autonomy Technologies 20232
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	Johanna Fröhlich Prof. Dr.-Ing. Ralf Müller	

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 Kanaäle 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 everydays 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 irreguäre Knotenordnungsverteilungen. Die Studierenden transformieren Bildquellen zur Verbesserung verlustbehafteter Kompression iin den Frequenzbereich.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Networking & Collaboration - core modules Master of Science Autonomy Technologies 20232
10	**Method of examination**	Written examination (120 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	Vorlesung: MIMO Communication Systems (3 SWS) (SoSe 2026) Übung: MIMO Communication Systems - Tutorial (1 SWS) (SoSe 2026)	5 ECTS -
3	Lecturers	Hedieh Ajam Prof. Dr.-Ing. Robert Schober	

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: 1
9	**Module compatibility**	Networking & Collaboration - core modules Master of Science Autonomy Technologies 20232

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: 1
9	**Module compatibility**	Networking & Collaboration - core modules Master of Science Autonomy Technologies 20232
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	Vorlesung: Image and Video Compression (IVC) (4 SWS) (SoSe 2026) Übung: Übung zu Image and Video Compression (SoSe 2026)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Andre Kaup Anna Meyer	

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: 1
9	**Module compatibility**	Human-system Interfaces - specialization module Master of Science Autonomy Technologies 20232 Networking & Collaboration - specialization module Master of Science Autonomy Technologies 20232 Sensing & Perception - specialization module Master of Science Autonomy Technologies 20232
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** Commmunications systems design	**5 ECTS**
2	Courses / lectures	Vorlesung: Communications Systems Design (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Georg Fischer Dr.-Ing. Zhongju Li	

4	**Module coordinator**	Prof. Dr.-Ing. Georg Fischer Prof. Dr.-Ing. Norman Franchi 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**	semester: 1
9	**Module compatibility**	Networking & Collaboration - specialization module Master of Science Autonomy Technologies 20232
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 for this semester!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module for this semester!	

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 Selbstorganisiationsprinzipien 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**	semester: 1
9	**Module compatibility**	Networking & Collaboration - specialization module Master of Science Autonomy Technologies 20232
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	Übung: Mobile Communications - Tutorial (1 SWS) (SoSe 2026) Vorlesung: Mobile Communications (3 SWS) (SoSe 2026)	- 5 ECTS
3	Lecturers	Levi-Pascal Bohnacker Prof. Dr.-Ing. Ralf Müller	

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 antenuation 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: 1
9	**Module compatibility**	Networking & Collaboration - specialization module Master of Science Autonomy Technologies 20232
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	**Multiuser 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	Dr. Fardad Vakilipoor Takaloo Prof. Dr.-Ing. Ralf Müller	

4	**Module coordinator**	Prof. Dr.-Ing. Ralf Müller
5	**Contents**	Linear vs. nonlinear multiple-access, CDMA as a canoncal 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: 1
9	**Module compatibility**	Networking & Collaboration - specialization module Master of Science Autonomy Technologies 20232
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 Levi-Pascal Bohnacker	

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**	semester: 1

9	**Module compatibility**	Networking & Collaboration - specialization module Master of Science Autonomy Technologies 20232
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	Vorlesung: Channel Coding on Graphs (3,5 SWS) (SoSe 2026) Übung: Channel Coding on Graphs - Tutorial (0,5 SWS) (SoSe 2026)	5 ECTS -
3	Lecturers	Prof. Dr. Laura Cottatellucci Christian Forsch	

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 Master of Science Autonomy Technologies 20232
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	Übung: Advanced Communication Networks - Tutorial (0,5 SWS) (SoSe 2026) Vorlesung: Advanced Communication Networks (3,5 SWS) (SoSe 2026)	- 5 ECTS
3	Lecturers	Christian Forsch Prof. Dr. Laura Cottatellucci	

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-Frobenious 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-Frobenious 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 Master of Science Autonomy Technologies 20232
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	Prof. Dr. Wolfgang Gerstacker	

4	**Module coordinator**	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 Master of Science Autonomy Technologies 20232
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	Vorlesung: Transmission and Detection for Advanced Mobile Communications (2 SWS) (SoSe 2026)	2,5 ECTS
3	Lecturers	Prof. Dr. Wolfgang Gerstacker	

4	**Module coordinator**	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 Diversitätsgewinnnen bei empfangsseitiger Antennendiversität • entwerfen Space-Time-Codierverfahren 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 Master of Science Autonomy Technologies 20232
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	Übung: Exercises to Approximate Computing (2 SWS) (SoSe 2026) Vorlesung: Approximate Computing (2 SWS) (SoSe 2026)	- 5 ECTS
3	Lecturers	Pierre-Louis Sixdenier Jose Juan Hernandez Morales Prof. Dr.-Ing. Jürgen Teich	

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 Master of Science Autonomy Technologies 20232
10	**Method of examination**	Variable The examination is based on the didactic nature of the module and comprises either a 30-minute oral examination or a 90-minute written examination. The decision on the form of examination will be announced in the semester in which the courses take place, no later than two weeks after the start of the lecture. In semesters in which no courses take place, the form of examination will be announced in studOn no later than two months before the repeat examination.
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	Vorlesung: Next Generation Mobile Communication Systems: 5G-Advanced and 6G (2 SWS) (SoSe 2026)	2,5 ECTS
3	Lecturers	Prof. Dr. Wolfgang Gerstacker Dr. Stefan Brück	

4	**Module coordinator**	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 zellularer 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 Master of Science Autonomy Technologies 20232
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

Planning & Control - Core modules

1	**Module name** 92519	**Robotics 1**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Robotics 1 (4 SWS) (SoSe 2026)	5 ECTS
3	Lecturers	Dr.-Ing. Andreas Völz	

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: 1
9	**Module compatibility**	Planning & Control - core modules Master of Science Autonomy Technologies 20232
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	Vorlesung mit Übung: Nonlinear Control Systems (4 SWS) (SoSe 2026)	5 ECTS
3	Lecturers	Prof. Dr.-Ing. Knut Graichen	

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: 1
9	**Module compatibility**	Planning & Control - core modules Master of Science Autonomy Technologies 20232
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	Vorlesung mit Übung: Numerical Optimization and Model Predictive Control (4 SWS) (SoSe 2026)	5 ECTS
3	Lecturers	Prof. Dr.-Ing. Knut Graichen	

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: 1
9	**Module compatibility**	Planning & Control - core modules Master of Science Autonomy Technologies 20232

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: 1

9	**Module compatibility**	Planning & Control - core modules Master of Science Autonomy Technologies 20232
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** 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 Master of Science Autonomy Technologies 20232
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: Collision detection, configuration space, local path planning, global path planning, time-optimal trajectory generation • 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: 1
9	**Module compatibility**	Planning & Control - specialization module Master of Science Autonomy Technologies 20232
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	Vorlesung mit Übung: Digitale Regelung (4 SWS) (SoSe 2026)	5 ECTS
3	Lecturers	Dr.-Ing. Andreas Michalka	

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 Master of Science Autonomy Technologies 20232
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	Vorlesung mit Übung: Schätzverfahren in der Regelungstechnik (4 SWS) (SoSe 2026)	5 ECTS
3	Lecturers	Prof. Dr.-Ing. Thomas Moor	

4	**Module coordinator**	Prof. Dr.-Ing. 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: 1
9	**Module compatibility**	Planning & Control - specialization module Master of Science Autonomy Technologies 20232
10	**Method of examination**	Written examination (90 minutes) Im SoSe 2026 findet ausnahmsweise eine mündliche Prüfung 30min statt.
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	Vorlesung mit Übung: Ereignisdiskrete Systeme (4 SWS) (SoSe 2026)	5 ECTS
3	Lecturers	Prof. Dr.-Ing. Thomas Moor Dr. Germano Schafaschek	

4	**Module coordinator**	Prof. Dr.-Ing. Thomas Moor
5	**Contents**	[English] Formal models of discrete-event systems (analysis) • languages of finite words, deterministic finite automata • timed event graphs, idempotent semirings, max-plus algebra Discrete-event controller design (synthesis) • representation of closed-loop systems, language inclusion specifications • controllability, supremal controllable sublanguages, nonblocking control • residuation theory, just-in-time contro • disturbance rejection, stabilisation, reference tracking [German] Formale Modelle ereignisdiskreter Systeme (Analyse) • reguläre Sprachen endlicher Wörter, deterministische endliche Automaten • zeitbehaftete Synchronisationsgraphen, idempotente Semiringe, Max-Plus-Algebra Entwurf ereignisdiskreter Regler (Synthese) • Darstellung des geschlossenen Regelkreises, Spracheinschließungsspezifikationen • Steuerbarkeit, supremale steuerbare Teilsprachen, blockierungsfreie Steuerung • Residuen-Theorie, Just-in-Time-Steuerung • Störungenskompensation, Stabilisierung, Folgeregelung
6	**Learning objectives and skills**	[English] Attending this course, participants • assess and verify fundamental facts regarding formal languages, automata, and max-plus algebra

		• obtain and interpret discrete-event models for simple technical processes, including specifications • obtain state equations describing the evolution of timed event graphs, and derive corresponding transfer functions • obtain maximally permissive controllers and interpret the resulting closed-loop behaviour • obtain just-in-time inputs resulting in optimal reference tracking • obtain feedback controllers leading to disturbance rejection and stabilisation [Deutsch] Teilnehmer dieser Veranstaltung • erklären, illustrieren und validieren Grundlagen formaler Sprachen, endlicher Automaten und der Max-Plus-Algebra • entwickeln ereignisdiskrete Modelle einfacher technischer Prozesse, einschließlich formaler Spezifikationen • überführen zeitbehaftete Synchronisationsgraphen in Zustandsdarstellungen, inkl. Übertragungsfunktion • entwerfen maximal permissive Regler und interpretieren das Verhalten des gschlossenen Regelkreises • entwerfen just-in-time Steuerungen zur optimalen Folgeregelung •
7	**Prerequisites**	[English] It is recommended that at least one of the following modules is completed before attending this module: • Regelungstechnik A (RT A) • Einführung in die Regelungstechnik (ERT) • Dynamical Systems and Control (DSC) [Deutsch] Es wird empfohlen, eines der folgenden Module zu absolvieren, bevor dieses Modul belegt wird: • Regelungstechnik A (Grundlagen) (RT A) • Einführung in die Regelungstechnik (ERT) • Dynamical Systems and Control (DSC)
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Planning & Control - specialization module Master of Science Autonomy Technologies 20232

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 english
16	**Bibliography**	• Wonham, W. M., Cai, K.: Supervisory Control of Discrete-Event Systems, Springer, 2019 • Hardouin, L., Cottenceau, B., Shang, Y., Raisch, J.: Control and State Estimation for Max-Plus Linear Systems, 2018

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: 1
9	**Module compatibility**	Planning & Control - specialization module Master of Science Autonomy Technologies 20232 Sensing & Perception - core modules Master of Science Autonomy Technologies 20232
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	Marc Hölle Prof. Dr. Vasileios Belagiannis Michele De Vita Leonhard Kraft	

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: 1

9	**Module compatibility**	Planning & Control - specialization module Master of Science Autonomy Technologies 20232 Sensing & Perception - core modules Master of Science Autonomy Technologies 20232
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	Vorlesung mit Übung: Pattern Analysis (4 SWS) (SoSe 2026)	5 ECTS
3	Lecturers	PD Dr.-Ing. Christian Riess Sheethal Bhat	

4	**Module coordinator**	PD Dr.-Ing. Christian Riess
5	**Contents**	This lecture is the sequel to the lecture *"Pattern Recognition"*. As such, it covers topics from the chapters 8-14 from the book *"Pattern Recognition and Machine Learning"* 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 Master of Science Autonomy Technologies 20232
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	Paula Andrea Pérez Toro 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 Master of Science Autonomy Technologies 20232
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 Tobshirani, 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** 94951	**Grundlagen der Robotik** Fundamentals of robotics	**5 ECTS**
2	Courses / lectures	Übung: Übung zu Grundlagen der Robotik (0 SWS) (SoSe 2026) Vorlesung: Grundlagen der Robotik (2 SWS) (SoSe 2026)	2,5 ECTS 2,5 ECTS
3	Lecturers	Dr.-Ing. Sebastian Reitelshöfer	

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**	semester: 1
9	**Module compatibility**	Planning & Control - specialization module Master of Science Autonomy Technologies 20232
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	Dr.-Ing. Sebastian Reitelshöfer Nina Merz	

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**	semester: 1
9	**Module compatibility**	Planning & Control - specialization module Master of Science Autonomy Technologies 20232
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	Übung: Rechnerübungen zu Verteilte Systeme (2 SWS) (SoSe 2026) Übung: Übungen zu Verteilte Systeme (2 SWS) (SoSe 2026) Vorlesung: Verteilte Systeme (2 SWS) (SoSe 2026)	- 2,5 ECTS 2,5 ECTS
3	Lecturers	Paul Bergmann Dr. rer. nat. Christian Berger	

4	**Module coordinator**	Dr. rer. nat. Christian Berger 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 Rechnergrenzen 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 Datenrepräsenationen. • 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: 1
9	**Module compatibility**	Planning & Control - specialization module Master of Science Autonomy Technologies 20232
10	**Method of examination**	Oral (30 minutes) 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**	Oral (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	Vorlesung: Advanced Topics in Deep Learning (4 SWS) (SoSe 2026) Übung: Supplements for Advanced Topics in Deep Learning (2 SWS) (SoSe 2026)	5 ECTS -
3	Lecturers	Prof. Dr. Vasileios Belagiannis Leonhard Kraft	

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 Master of Science Autonomy Technologies 20232
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.

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	Übung: Radar, RFID and Wireless Sensor Systems Exercises (2 SWS) (SoSe 2026) Vorlesung: Radar, RFID and Wireless Sensor Systems (2 SWS) (SoSe 2026)	- 5 ECTS
3	Lecturers	Dr.-Ing. Christian Carlowitz Prof. Dr.-Ing. Martin Vossiek	

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), autonoumous 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: 1
9	**Module compatibility**	Sensing & Perception - core modules Master of Science Autonomy Technologies 20232
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**	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: 1
9	**Module compatibility**	Planning & Control - specialization module Master of Science Autonomy Technologies 20232 Sensing & Perception - core modules Master of Science Autonomy Technologies 20232
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: 1
9	**Module compatibility**	Human-system Interfaces - specialization module Master of Science Autonomy Technologies 20232 Sensing & Perception - core modules Master of Science Autonomy Technologies 20232
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	Marc Hölle Prof. Dr. Vasileios Belagiannis Michele De Vita Leonhard Kraft	

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: 1

9	**Module compatibility**	Planning & Control - specialization module Master of Science Autonomy Technologies 20232 Sensing & Perception - core modules Master of Science Autonomy Technologies 20232
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	Vorlesung: Image and Video Compression (IVC) (4 SWS) (SoSe 2026) Übung: Übung zu Image and Video Compression (SoSe 2026)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Andre Kaup Anna Meyer	

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: 1
9	**Module compatibility**	Human-system Interfaces - specialization module Master of Science Autonomy Technologies 20232 Networking & Collaboration - specialization module Master of Science Autonomy Technologies 20232 Sensing & Perception - specialization module Master of Science Autonomy Technologies 20232
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	PD Dr. Patrick Krauß Prof. Dr. Andreas Kist Prof. Dr. Tim Weyrich 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: 1
9	**Module compatibility**	Sensing & Perception - specialization module Master of Science Autonomy Technologies 20232
10	**Method of examination**	Written examination (60 minutes)

		Tutorial achievement 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**	Written examination (100%) Tutorial achievement (pass/fail)
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 Master of Science Autonomy Technologies 20232
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. • o M. Richards, Fundamentals of Radar Signal Processing, McGraw-Hill, 2nd ed., 2014 o I. Cumming, F. Wong, Digital Processing of Synthetic Aperture Radar Data, Artech House, 2004 o J. Curlander, R. Donough, Synthetic Aperture Radar Systems & Signal Processing, Wiley, 1991 o F. Ulaby, D. Long, Microwave Radar and Radiometric Remote Sensing, Michigan Press, 2014 o C. Oliver, S. Quegan, Understanding Synthetic Aperture Images, Scitech, 2004 o H. Van Trees, Optimum Array Processing, Wiley Interscience, 2002 o J. Guerci, Space-Time Adaptive Processing for Radar, Artech House, 2nd ed., 2015 o R. Hanssen, Radar Interferometry, Kluwer Academic Publishers, 2001 o 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	Vorlesung: Advanced Optical Communication Systems (2 SWS) Übung: Advanced Optical Communication Systems Exercises (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Bernhard Schmauß Esther Renner Lukas Bernhardt	

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 designes of optical transmission systems. • are abke 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 Master of Science Autonomy Technologies 20232
10	**Method of examination**	Oral (30 minutes) Examinbation: 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
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 Master of Science Autonomy Technologies 20232
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	Vorlesung mit Übung: Perception in Robotics (2 SWS) (SoSe 2026) Übung: Supplements for Perception in Robotics (SoSe 2026)	- -
3	Lecturers	Prof. Dr. Vasileios Belagiannis Marc Hölle	

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 Master of Science Autonomy Technologies 20232
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. "Probalistic 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	Vorlesung: Speech and Language Understanding (VHB-Kurs) (2 SWS)	5 ECTS
3	Lecturers	Paula Andrea Pérez Toro	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Maier
5	**Contents**	Please note: This module is held 100% online via the Virtual University of Bavaria ([1]www.vhb.org) under the title “Fundamentals of Speech Processing”. Please register for the exam via the VHB website as well as via Campo. 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 Merkmalgewinnung, 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 Master of Science Autonomy Technologies 20232
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**	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 • o 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	Vorlesung: Transformationen in der Signalverarbeitung (2 SWS) (SoSe 2026)	2,5 ECTS
3	Lecturers	PD Dr.-Ing. Jürgen Seiler	

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 • asses 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 Master of Science Autonomy Technologies 20232
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** 713618	**Computer vision**	**5 ECTS**
2	Courses / lectures	Übung: Computer Vision Exercise (4 SWS) (SoSe 2026) Vorlesung: Computer Vision (2 SWS) (SoSe 2026)	2,5 ECTS 2,5 ECTS
3	Lecturers	Dr.-Ing. Vanessa Klein Muhammad Sohail Prof. Dr. Tim Weyrich Prof. Dr. Bernhard Egger	

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 Master of Science Autonomy Technologies 20232
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** 267499	**Linear and non-linear fibre optics**	**5 ECTS**
2	Courses / lectures	Übung: Linear and non-linear fibre optics: Exercise (2 SWS) (SoSe 2026) Vorlesung: Linear and non-linear fibre optics (2 SWS) (SoSe 2026)	- 5 ECTS
3	Lecturers	Alex Kariuki Muthumbi Prof. Dr.-Ing. Bernhard Schmauß	

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 Master of Science Autonomy Technologies 20232
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

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 Master of Science Autonomy Technologies 20232
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 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 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 Master of Science Autonomy Technologies 20232
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 Dr. Léa Boillereaux	

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 Master of Science Autonomy Technologies 20232
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	Currently no teaching units are offered for this module. For further information on teaching units please contact the module managers.	
3	Lecturers		

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 Master of Science Autonomy Technologies 20232
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** 47537	**Seminar Wearable Devices for Sensing the Neural Control of Movement**	**5 ECTS**
2	Courses / lectures	Seminar: Seminar on Wearable Devices For Sensing the Neural Control of Movement (MyoDesign) (4 SWS)	5 ECTS
3	Lecturers	Vlad Cnejevici Mounir Shaib Prof. Dr. Alessandro Del Vecchio	

4	**Module coordinator**	Prof. Dr. Alessandro Del Vecchio
5	**Contents**	• Analysis of muscle sensing wearable devices (e.g. electromyography, force myography etc.) • Electronics, software and CAD design of a wearable system • Signal filtering, amplification, data communication protocol (e.g., Bluetooth, Wi-Fi) and housing design • Examples of muscle sensing devices on the market and in literature
6	**Learning objectives and skills**	**After completing the module, students** • Can design and implement electronic circuits for biosignal sensing • Can perform design steps (e.g. CAD design, circuit prototyping, communication protocol implementation etc.) while working in a team • Can perform a literature research • Can produce a written report in accordance with scientific standards • Can give a scientific presentation about their assigned topic
7	**Prerequisites**	General knowledge of circuit design, communication protocols (e.g. Bluetooth, Wi-Fi) and / or CAD design would be useful.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Human-system Interfaces - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232 ·B. Sc. and M. Sc. Medizintechnik ·B. Sc. and M. Sc. Elektrotechnik –Elektronik – Informationstechnik ·B.Sc. and M. Sc. Computional Engineering ·B.Sc. and M. Sc. Mechincal Engineering B.Sc. and M. Sc. Mechatronics
10	**Method of examination**	Seminar achievement

		Written Report (5 - 10 pages), Project Presentation (30 minutes)
11	**Grading procedure**	Seminar achievement (100%) Written Report (60%) and Live Presentation (40%)
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**	Merletti, R., and G. L. Cerone. "Tutorial. Surface EMG detection, conditioning and pre-processing: Best practices." Journal of Electromyography and Kinesiology 54 (2020): 102440. DOI: https://doi.org/10.1016/j.jelekin.2020.102440 S. Koutsoftidis, D. Y. Barsakcioglu, K. Petkos, D. Farina and E. M. Drakakis, "Myolink: A 128-Channel, 18 nV/Hz−−−√, Embedded Recording System, Optimized for High-Density Surface Electromyogram Acquisition," in IEEE Transactions on Biomedical Engineering, vol. 69, no. 11, pp. 3389-3396, Nov. 2022, doi: 10.1109/TBME.2022.3170025. DOI: https://doi.org/10.1109/TBME.2022.3170025 G. L. Cerone, A. Botter, T. Vieira and M. Gazzoni, "Design and Characterization of a Textile Electrode System for the Detection of High-Density sEMG," in IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 29, pp. 1110-1119, 2021, doi: 10.1109/TNSRE.2021.3086860. DOI: https://doi.org/10.1109/TNSRE.2021.3086860

1	**Module name** 47591	**Seminar Cognitive Surgical Robotics**	**5 ECTS**
2	Courses / lectures	Hauptseminar: Seminar Cognitive Surgical Robotics (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Franziska Mathis-Ullrich	

4	**Module coordinator**	Prof. Dr. Franziska Mathis-Ullrich
5	**Contents**	In contrast to industrial robots, surgical robots cannot follow pre-programmed motions. In surgical applications, next-generation learning robots will need to continuously sense their environment through sensors, interpret this data to reason about the environment, and update their behaviour accordingly, informed by previously learned strategies. (i.e., machine learning and AI). In the style of the tradition sense-plan-act model of robot control, cognitive surgical robotics encompasses methods that: • enable surgical robots to process sensor information to a higher level of abstraction, • reason about their behaviour in the context of an environment state and task to solve, • plan actions, and • execute the planned actions in their environment. These methods have to take into account the particular challenges of surgical applications, such as interaction with deformable objects, challenging visuals (e.g. blood, reflections, occlusions, smoke, …), complex long duration tasks, and virtually no room for error recovery. During the seminar, students will conduct a thorough literature research for a specific topic provided. The research study includes finding, understanding, and summarizing the state of the art as well as a critical review and analysis concerning limitations and potential of various methods.
6	**Learning objectives and skills**	Students • learn methods to effectively execute a literature study and are provided with the basic rules to cite research papers in a scientific report. • independently research state-of-the-art literature on the topic of cognitive and cognition-guided robots in surgery. • analyse their findings and critically evaluate the potential and limitations thereof. • excerpt the essential findings from their literature search and analysis and summarize them according to the level of knowledge of the fellow students.
7	**Prerequisites**	General knowledge in the areas AI and robotics will be an advantage.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Human-system Interfaces - Seminar & Laboratory Master of Science Autonomy Technologies 20232

		Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Seminar achievement Presentation and written report. The students will give a scientific presentation in English according to international conference standards. Written report: 14 - 15 pages (on our template) Presentation: 10 min presentation and 10 min discussion of the topic Attendance at the seminar student colloquium
11	**Grading procedure**	Seminar achievement (100%) Report: 50%, Presentation: 50%
12	**Module frequency**	Every semester
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**	

1	**Module name** 44143	**Seminar Machine Learning in Movement Analysis**	**5 ECTS**
2	Courses / lectures	Seminar: Machine Learning in Movement Analysis (3 SWS)	5 ECTS
3	Lecturers	Alexander Weiß Prof. Dr. Anne Koelewijn	

4	**Module coordinator**	Prof. Dr. Anne Koelewijn
5	**Contents**	The goal of this module is to teach students how machine learning is used in movement analysis. While many algorithms exist for pose estimation with computer graphics applications, machine learning is only used sparsely in biomechanical movement analysis. Then, not only the pose is important, but also the kinetic variables, i.e., the internal forces and moments that cause movement. Its application to estimate those variables is difficult since it is challenging to record or estimate accurate ground truth data and due to the similarity of motion between individuals. The module will start with several introductory units. Then, the students will select a paper with associated publicly available dataset (and code), in which machine learning is applied for biomechanical movement analysis. The students will present the paper to the other students, including an approach to improve or add to the paper's results. Next, the students will implement this approach and write a report about the implemented methods.
6	**Learning objectives and skills**	Knowledge: • Know common structures of movement analysis data • Know state of the art measurement approaches • Know the variable types that are relevant in movement analysis • Know commonly used approaches to apply machine learning in movement analysis • Know effective approaches to analyse machine learning model performance in movement analysis Understanding: • Understand the limitations of different measurement systems and resulting ground truth data. • Understand the relationship between different variable types and the related biomechanical applications • Understand the advantages and disadvantages of different evaluation approaches. Application: • Create an academic presentation about a journal/conference paper • Write an academic report about an implementation project • Apply known machine learning algorithms to movement analysis data • Able to select an analysis approach given a research question

		Analyse: Analyse movement data to evaluate machine learning algorithms
7	**Prerequisites**	• No compulsory prerequisite courses • Recommended background knowledge are on biomechanics and movement analysis (e.g., Gait Analysis and Simulation, GAS) as well as in machine learning (e.g., Machine Learning for Time Series, MLTS)
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Human-system Interfaces - Seminar & Laboratory Master of Science Autonomy Technologies 20232 • M. Sc. Medical Engineering • M. Sc. Artificial Intelligence • M. Sc. Computer Science • M. Sc. Data Science
10	**Method of examination**	Seminar achievement The students will give a presentation including a Q&A. The presentation will be 30 minutes (20+10).[CB1] The students will write a report of about 3000 words.
11	**Grading procedure**	Seminar achievement (100%) The grading will be based on the % score that is achieved in the presentation and the written report. The % score of the presentation and the written report both count 50%. E.g., a student who scores 90% on the written report and 81% on the presentation will receive a final score of 86%, which equals the grade of 1.7. A student who scores 20% and 70% will receive a final score of 45%, which equals the grade of 5.0.
12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Recommended reading: • Dorschky, E., Nitschke, M., Martindale, C. F., Van den Bogert, A. J., Koelewijn, A. D., and Eskofier, B. M. (2020). Cnn-based estimation of sagittal plane walking and running biomechanics from measured and simulated inertial sensor data. Front. Bioeng. Biotechnol. 8, 604. • Fleischmann, S., Dietz, S., Shanbhag, J., Wuensch, A., Nitschke, M., Miehling, J., ... & Koelewijn, A. D. (2024). Exploring Dataset Bias and Scaling Techniques in Multi-Source Gait Biomechanics: An Explainable Machine Learning Approach. ACM Transactions on Intelligent Systems and Technology, 16(1), 1-19. • Mundt, M., Johnson, W. R., Potthast, W., Markert, B., Mian, A., and Alderson, J. (2021). A comparison of three neural network

		approaches for estimating joint angles and moments from inertial measurement units. Sensors 21, 4535. • Conte Alcaraz, J., Moghaddamnia, S., and Peissig, J. (2021). Efficiency of deep neural networks for joint angle modeling in digital gait assessment. EURASIP J. Adv. Signal Process. 2021, 10–20. • Bicer, M., Phillips, A. T., Melis, A., McGregor, A. H., and Modenese, L. (2022). Generative deep learning applied to biomechanics: a new augmentation technique for motion capture datasets. J. biomechanics 144, 111301. • Mundt, M., Thomsen, W., Witter, T., Koeppe, A., David, S., Bamer, F., et al. (2020). Prediction of lower limb joint angles and moments during gait using artificial neural networks. Med. and Biol. Eng. and Comput. 58, 211–225.

Networking & Collaboration - Seminar & laboratory

1	**Module name** 97651	**Laborpraktikum Image and Video Compression** Laborpraktikum Multimediakommunikation	**2,5 ECTS**
2	Courses / lectures	Praktikum: Lab Course Image and Video Compression (3 SWS) (WiSe 2026)	2,5 ECTS
3	Lecturers	Marc Windsheimer	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup
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 Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
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 for this semester!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module for this semester!	

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 language Python. The course consists of 5 guided experiments in which students work on programming problems in groups of two. The following topics are treated in theses sessions: • Digital signals and A/D conversion • The DFT and spectral analysis • Non-recursive filters and filter banks • Recursive filters • Adaptive filters. After the lab experiements, each group works has to complete an individual project from the field of digital signal processing.
6	**Learning objectives and skills**	The students • create Python programs for the each experiements and, by this, apply knowledge acquired in the DSP lecutre 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**	The course requires knowledge in Python programming and basic knowledge in digital signal processing. Attendance of the DSP lecture is strongly recommended but not mandatory.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Practical achievement The preparation, as well as the results of the past experiment will be examined by a short test at the beginning of each lab session. For passing the lab course, a minimum number of points from the tests and the project is required.
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**	english
16	**Bibliography**	Main references: 1. H. Löllmann: "Lecture Notes Digital Signal Processing", MultimediaCommunications and Signal Processing, FAU, 2025 2. A. V. Oppenheim, R.W. Schafer and J. R.Buck: "Discrete-Time SignalProcessing", 2nd edition, Prentice Hall, 1999. Further references are provided by the course material.

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 for this semester!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module for this semester!	

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 Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
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** 92527	**Joint communications and sensing in wireless systems**	**2,5 ECTS**
2	Courses / lectures	Hauptseminar: Joint Communications and Sensing in Wireless Systems (2 SWS) (SoSe 2026)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Norman Franchi Maximilian Lübke Prof. Dr.-Ing. Martin Vossiek Prof. Dr.-Ing. Georg Fischer Prof. Dr.-Ing. Robert Schober	

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 Master of Science Autonomy Technologies 20232
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	Praktikum: Praktikum Mobilkommunikation / Lab Course Mobile Communications - Group 1 (3 SWS) (SoSe 2026) Praktikum: Praktikum Mobilkommunikation / Lab Course Mobile Communications - Group 2 (3 SWS) (SoSe 2026)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr. Wolfgang Gerstacker	

4	**Module coordinator**	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
		  ◦ Entzerrerdesign 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 Master of Science Autonomy Technologies 20232
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) Attendance of the lab session is mandatory.	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Sebastian Schlecht Dr.-Ing. Heinrich Löllmann	

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 language Python. The course consists of 5 guided experiments in which students work on programming problems in groups of two. The following topics are treated in theses sessions: • Digital signals and A/D conversion • The DFT and spectral analysis • Non-recursive filters and filter banks • Recursive filters • Adaptive filters. After the lab experiements, each group works works on an individual project from the field of digital signal processing. To complete the project, the Python implementation of the assigned task and a short report (3-5 pages) about the project needs to be submitted.
6	**Learning objectives and skills**	The students • create Python programs for the each experiements and, by this, apply knowledge acquired in the DSP lecutre 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**	The course requires knowledge in Python programming and basic knowledge in digital signal processing. Attendance of the DSP lecture is strongly recommended but not mandatory.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Practical achievement The preparation, as well as the results of the past experiment will be examined by a short test at the beginning of each lab session. For

		passing the lab course, a minimum number of points from the tests and and sucessfull completion of the 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**	Main references: 1. H. Löllmann: "Lecture Notes Digital Signal Processing", MultimediaCommunications and Signal Processing, FAU, 2025 2. A. V. Oppenheim, R.W. Schafer and J. R.Buck: "Discrete-Time SignalProcessing", 2nd edition, Prentice Hall, 1999. Further references are provided by the script for this lab course (which is handed out at the introductory meeting.

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 Master of Science Autonomy Technologies 20232
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 Übertragunsstrecken 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 Empfängeralgorithemen.
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 Master of Science Autonomy Technologies 20232
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.)

1	**Module name** 92356	**Praktikum Communications Systems Design** Laboratory course: Communications systems design	**2,5 ECTS**
2	Courses / lectures	Praktikum: Praktikum Communications Systems Design	2,5 ECTS
3	Lecturers	Jonas Bönsch Dr.-Ing. Zhongju Li	

4	**Module coordinator**	Arslan Ali Prof. Dr.-Ing. Georg Fischer Prof. Dr.-Ing. Norman Franchi
5	**Contents**	The lab course is based on the GNU Radio software platform. It includes a general introduction into GNU Radio, Python programming and Software Defined Radios (SDRs), as well as a more thorough introduction into USRPs. The students learn how to set up pure simulations of communication systems in Gnu Radio, how to use it in conjunction with Software Defined Radios and how to develop and test custom modules in Python. Regarding Gnu Radio the usage of different data types, variables, structures (e.g. vectors and streams), hierarchical development and flow control are part of the course. The course is structured into 8 exercises which first cover different modulation schemes like AM, PAM, and OFDM. In the later part of the course topics of practical relevance like synchronization (time, frequencye, phase, frame) and equalization are covered. One synchronization scheme for OFDM is to be implemented by the students in Python. Most exercises have the goal to transmit audio data, first in a simulation, then in a loopback with one device and later between several devices. Setups to evaluate metrics like eye diagrams and EVM are introduced in a practical manner. Passing an introduction test is prerequisite for the participation in the lab course.
6	**Learning objectives and skills**	Students can • bridge the gap between communications theory, analog/digital baseband, and RF design • develop quick and flexible prototypes for real-time communications systems and standards using SDR solutions • determine the design parameters and assess the interaction between various analog and digital parts • create efficient Tx/Rx programs and signal processing algorithms in GNU Radio • implement channel estimation and equalization algorithms in TDD and FDD systems • demonstrate OFDM based systems • quantify and evaluate system performance using EVM and impairments analysis
7	**Prerequisites**	Prerequisite for this course is proper knowledge in the fundamentals of digital communications and digital signal processing.

8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Practical achievement At the begin of the lab course, the prerequisites are tested with a short (15 min) written test. Passing this test is required to participate in the experiments. The lab course itself consists of six experiments. At the end of every experiment the students have to present their respective final result. The understanding of the theoretical concepts will be check orally.
11	**Grading procedure**	Practical achievement (pass/fail)
12	**Module frequency**	Every semester The lab course takes place as a block course (1 week) in each semester.
13	**Workload in clock hours**	Contact hours: 40 h Independent study: 35 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 878210	**Lab course machine learning in signal processing**	**2,5 ECTS**
2	Courses / lectures	Praktikum: Lab Course Machine Learning in Signal Processing (4 SWS) (SoSe 2026)	2,5 ECTS
3	Lecturers	Marc Hölle Prof. Dr. Vasileios Belagiannis Rohan Asthana Michele De Vita Leonhard Kraft	

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 corse.
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**	Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
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) Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning. 2) Friedman, J., Hastie, T., & Tibshirani, R. (2001). The elements of statistical learning. 3) Raschka, S., Liu, Y. H., Mirjalili, V., & Dzhulgakov, D. (2022). Machine Learning with PyTorch and Scikit-Learn: Develop machine learning and deep learning models with Python.

1	**Module name** 47537	**Seminar Wearable Devices for Sensing the Neural Control of Movement**	**5 ECTS**
2	Courses / lectures	Seminar: Seminar on Wearable Devices For Sensing the Neural Control of Movement (MyoDesign) (4 SWS)	5 ECTS
3	Lecturers	Vlad Cnejevici Mounir Shaib Prof. Dr. Alessandro Del Vecchio	

4	**Module coordinator**	Prof. Dr. Alessandro Del Vecchio
5	**Contents**	• Analysis of muscle sensing wearable devices (e.g. electromyography, force myography etc.) • Electronics, software and CAD design of a wearable system • Signal filtering, amplification, data communication protocol (e.g., Bluetooth, Wi-Fi) and housing design • Examples of muscle sensing devices on the market and in literature
6	**Learning objectives and skills**	**After completing the module, students** • Can design and implement electronic circuits for biosignal sensing • Can perform design steps (e.g. CAD design, circuit prototyping, communication protocol implementation etc.) while working in a team • Can perform a literature research • Can produce a written report in accordance with scientific standards • Can give a scientific presentation about their assigned topic
7	**Prerequisites**	General knowledge of circuit design, communication protocols (e.g. Bluetooth, Wi-Fi) and / or CAD design would be useful.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Human-system Interfaces - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232 ·B. Sc. and M. Sc. Medizintechnik ·B. Sc. and M. Sc. Elektrotechnik –Elektronik – Informationstechnik ·B.Sc. and M. Sc. Computional Engineering ·B.Sc. and M. Sc. Mechincal Engineering B.Sc. and M. Sc. Mechatronics
10	**Method of examination**	Seminar achievement

		Written Report (5 - 10 pages), Project Presentation (30 minutes)
11	**Grading procedure**	Seminar achievement (100%) Written Report (60%) and Live Presentation (40%)
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**	Merletti, R., and G. L. Cerone. "Tutorial. Surface EMG detection, conditioning and pre-processing: Best practices." Journal of Electromyography and Kinesiology 54 (2020): 102440. DOI: https://doi.org/10.1016/j.jelekin.2020.102440 S. Koutsoftidis, D. Y. Barsakcioglu, K. Petkos, D. Farina and E. M. Drakakis, "Myolink: A 128-Channel, 18 nV/Hz−−−√, Embedded Recording System, Optimized for High-Density Surface Electromyogram Acquisition," in IEEE Transactions on Biomedical Engineering, vol. 69, no. 11, pp. 3389-3396, Nov. 2022, doi: 10.1109/TBME.2022.3170025. DOI: https://doi.org/10.1109/TBME.2022.3170025 G. L. Cerone, A. Botter, T. Vieira and M. Gazzoni, "Design and Characterization of a Textile Electrode System for the Detection of High-Density sEMG," in IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 29, pp. 1110-1119, 2021, doi: 10.1109/TNSRE.2021.3086860. DOI: https://doi.org/10.1109/TNSRE.2021.3086860

1	**Module name** 47591	**Seminar Cognitive Surgical Robotics**	**5 ECTS**
2	Courses / lectures	Hauptseminar: Seminar Cognitive Surgical Robotics (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Franziska Mathis-Ullrich	

4	**Module coordinator**	Prof. Dr. Franziska Mathis-Ullrich
5	**Contents**	In contrast to industrial robots, surgical robots cannot follow pre-programmed motions. In surgical applications, next-generation learning robots will need to continuously sense their environment through sensors, interpret this data to reason about the environment, and update their behaviour accordingly, informed by previously learned strategies. (i.e., machine learning and AI). In the style of the tradition sense-plan-act model of robot control, cognitive surgical robotics encompasses methods that: • enable surgical robots to process sensor information to a higher level of abstraction, • reason about their behaviour in the context of an environment state and task to solve, • plan actions, and • execute the planned actions in their environment. These methods have to take into account the particular challenges of surgical applications, such as interaction with deformable objects, challenging visuals (e.g. blood, reflections, occlusions, smoke, …), complex long duration tasks, and virtually no room for error recovery. During the seminar, students will conduct a thorough literature research for a specific topic provided. The research study includes finding, understanding, and summarizing the state of the art as well as a critical review and analysis concerning limitations and potential of various methods.
6	**Learning objectives and skills**	Students • learn methods to effectively execute a literature study and are provided with the basic rules to cite research papers in a scientific report. • independently research state-of-the-art literature on the topic of cognitive and cognition-guided robots in surgery. • analyse their findings and critically evaluate the potential and limitations thereof. • excerpt the essential findings from their literature search and analysis and summarize them according to the level of knowledge of the fellow students.
7	**Prerequisites**	General knowledge in the areas AI and robotics will be an advantage.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Human-system Interfaces - Seminar & Laboratory Master of Science Autonomy Technologies 20232

		Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Seminar achievement Presentation and written report. The students will give a scientific presentation in English according to international conference standards. Written report: 14 - 15 pages (on our template) Presentation: 10 min presentation and 10 min discussion of the topic Attendance at the seminar student colloquium
11	**Grading procedure**	Seminar achievement (100%) Report: 50%, Presentation: 50%
12	**Module frequency**	Every semester
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**	

Planning & Control - Seminar & laboratory

1	**Module name** 92338	**Lab Course Automatic Control I** Laboratory course: Automatic Control I	**2,5 ECTS**
2	Courses / lectures	Praktikum: Lab Course Automatic Control I (3 SWS)	-
3	Lecturers	Dr.-Ing. Andreas Michalka	

4	**Module coordinator**	Prof. Dr.-Ing. Knut Graichen
5	**Contents**	This lab course consists of six experiments on the following topics: • Analysis of control loops using Matlab/Simulink (two sessions) • Control design for a magnetic levitation system • Control design for an elastically mounted rotary arm • Active suspension control for a quarter car model • Control design for a two-tank system
6	**Learning objectives and skills**	The students are able to • apply methods from an introductory control lecture in simulations and on experimental setups • interpret and evaluate the experimental results • handle tools and devices from control engineering
7	**Prerequisites**	Recommended modules "Regelungstechnik A (Grundlagen)" or "Dynamical Systems and Control"
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Practical achievement • There are 6 experiments to complete. 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 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. • To pass the course, 6 sufficient experiment preparations and 6 sufficient experiment executions are required. • One unsuccessful session can be repeated at the end of the course. • The successful participation in introductory instructions and exercises on the laboratory work and the fundamentals of linear control is required for further participation in the course.
11	**Grading procedure**	Practical achievement (100%)
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**	english
16	**Bibliography**	

1	**Module name** 92339	**Lab Course Automatic Control II** Laboratory course: Automatic Control II	**2,5 ECTS**
2	Courses / lectures	Praktikum: Praktikum Regelungstechnik II / Lab Course Automatic Control II (3 SWS)	-
3	Lecturers	Dr.-Ing. Andreas Völz	

4	**Module coordinator**	Prof. Dr.-Ing. Knut Graichen Dr.-Ing. Andreas Völz
5	**Contents**	This lab course covers advanced control methods that are applied to different experimental setups. Students have to choose three out of five experiments, each one spanning two sessions. • Digitale Regelungen: inverted pendulum (two sessions) • Nonlinear control systems: laboratory crane and ball-on-plate (one session each) • Numerical optimization and model predictive control: ball-on-plate and laboratory crane (one session each) • Robotics 1: Franka Emika robot (two sessions) • Ereignisdiskrete Systeme: elevator model (two sessions)
6	**Learning objectives and skills**	The students are able to • apply methods from three advanced control lectures in simulations and on experimental setups • interpret and evaluate the experimental results in depth • handle state-of-the-art tools and devices of control engineering
7	**Prerequisites**	It is recommended to have attended at least three of the following five advanced lectures from the group "Digitale Regelungen", "Nonlinear Control Systems", "Numerical Optimization and Model Predictive Control", "Robotics 1" and "Ereignisdiskrete Systeme" prior to the lab course.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Practical achievement • At the start of the course three out of five lectures have to be chosen. For each lecture two experiments need to be completed. 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 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. • To pass the course, 6 sufficient experiment preparations and 6 sufficient experiment executions are required. • One unsuccessful session can be repeated at the end of the course.

11	**Grading procedure**	Practical achievement (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**	german english
16	**Bibliography**	

1	**Module name** 878210	**Lab course machine learning in signal processing**	**2,5 ECTS**
2	Courses / lectures	Praktikum: Lab Course Machine Learning in Signal Processing (4 SWS) (SoSe 2026)	2,5 ECTS
3	Lecturers	Marc Hölle Prof. Dr. Vasileios Belagiannis Rohan Asthana Michele De Vita Leonhard Kraft	

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 corse.
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**	Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
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) Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning. 2) Friedman, J., Hastie, T., & Tibshirani, R. (2001). The elements of statistical learning. 3) Raschka, S., Liu, Y. H., Mirjalili, V., & Dzhulgakov, D. (2022). Machine Learning with PyTorch and Scikit-Learn: Develop machine learning and deep learning models with Python.

1	**Module name** 92341	**Seminar Modern Control Methods** Seminar: Modern control methods	**2,5 ECTS**
2	Courses / lectures	Seminar: Seminar Modern Control Methods (2 SWS)	-
3	Lecturers	Dr.-Ing. Andreas Völz	

4	**Module coordinator**	Prof. Dr.-Ing. Knut Graichen Prof. Dr.-Ing. Thomas Moor
5	**Contents**	In this seminar, students will perform a literature search on a recent research topic in the broader field of automatic control. Findings are to be summarized by a written report and by a class room presentation. All participants contribute to a critical discussion of the presented results. The specific topics are announced at the beginning of the semester.
6	**Learning objectives and skills**	The students are able to • conduct a literature research on a recent topic in the field of automatic control and appreciate the scientific contribution • summarize the scientific contribution in a written report and evaluate it in depth • prepare a presentation for a professional audience • perform the presentation in free speech and within a given time • present the scientific contribution clearly and to convince a professional audience of pros and cons • reflect on their contribution to the discussions following the individual presentations
7	**Prerequisites**	The modules "Regelungstechnik A" and "Regelungstechnik B" or "Dynamical Systems and Control" are recommended.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Seminar achievement • Attendance is required for the initial meeting and the seminar presentations. • The written report (about 10 pages) accounts for 50% of the final grade. • The seminar presentation (20 min. + about 10 min. discussion) accounts for the other 50% of the final grade.
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** 92342	**Seminar Mobile Robotics** Seminar: Mobile robotics	**2,5 ECTS**
2	Courses / lectures	No courses / lectures available for this module for this semester!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module for this semester!	

4	**Module coordinator**	Prof. Dr.-Ing. Knut Graichen
5	**Contents**	In this course, tasks from the field of mobile robotics are analyzed, developed, and practically implemented on a Boston Dynamics Spot. The results of a literature search as well as of their implementation are summarized by a written report and by a class room presentation.
6	**Learning objectives and skills**	The students are able to • explain and apply scientific basics as well as specialized and in-depth knowledge in the field of mobile robotics • conduct largely independent application-oriented projects based on broad and specialized research methodologies of mobile robotics • work cooperatively and responsibly in groups and critically reflect and expand their own cooperative behaviour in groups • present complex technical content clearly and in a way that is appropriate for the audience and present arguments in a critical and reflective manner
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Seminar achievement • Attendance is required for the initial meeting and the seminar presentations. • The written report (about 10 pages) accounts for 50% of the final grade. • The seminar presentation (20 min. + about 10 min. discussion) accounts for the other 50% of the final grade.
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**	german english
16	**Bibliography**	

1	**Module name** 92374	**Seminar on Selected Topics in Machine Learning**	**2,5 ECTS**
2	Courses / lectures	Seminar: Seminar on Selected Topics in Machine Learning (2 SWS) (SoSe 2026) Seminar: Seminar on Selected Topics in Machine Learning (2 SWS) (WiSe 2026) The participants must be present at all in-person events.	2,5 ECTS 2,5 ECTS
3	Lecturers	Marc Hölle Marc Hölle Prof. Dr. Vasileios Belagiannis Rohan Asthana Michele De Vita Leonhard Kraft	

4	**Module coordinator**	Prof. Dr. Vasileios Belagiannis
5	**Contents**	The students will study, understand, and present scientific publications from the literature on machine learning and deep learning. At the end of the seminar, the student will be able to summarise and present a publication. The seminar covers a wide range of research topics in the field of machine learning and deep learning, including generative and foundation models, different types of learning and applications machine learning.
6	**Learning objectives and skills**	The students will learn to: • Conduct literature reviews. • Present and analyse a scientific topic. • Write a report on a specific problem. • Discuss and communicate research findings.
7	**Prerequisites**	Basic knowledge in Machine Learning and Deep Learning beneficial
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Seminar achievement The assigned topic must be presented at the end of the seminar in a talk (15 to 20 minutes) and presented in a written report (5 to 10 pages).
11	**Grading procedure**	Seminar achievement (100%) For the final grade, the presentation is weighted at 80% and the submitted report at 20%.
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**	Literature research is one of the learning objectives of the seminar. In the event that more in-depth literature is required, this will be made available during the seminar.

1	**Module name** 47657	**Legged Locomotion of Robots + Laborprojekt (LLR-L)** Legged locomotion of robots + laboratory project (LLR-L)	**5 ECTS**
2	Courses / lectures	Seminar: Legged Locomotion of Robots (2 SWS) (SoSe 2026)	2,5 ECTS
3	Lecturers	Prof. Dr. Anne Koelewijn	

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**	semester: 3
9	**Module compatibility**	Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232
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** 47537	**Seminar Wearable Devices for Sensing the Neural Control of Movement**	**5 ECTS**
2	Courses / lectures	Seminar: Seminar on Wearable Devices For Sensing the Neural Control of Movement (MyoDesign) (4 SWS)	5 ECTS
3	Lecturers	Vlad Cnejevici Mounir Shaib Prof. Dr. Alessandro Del Vecchio	

4	**Module coordinator**	Prof. Dr. Alessandro Del Vecchio
5	**Contents**	• Analysis of muscle sensing wearable devices (e.g. electromyography, force myography etc.) • Electronics, software and CAD design of a wearable system • Signal filtering, amplification, data communication protocol (e.g., Bluetooth, Wi-Fi) and housing design • Examples of muscle sensing devices on the market and in literature
6	**Learning objectives and skills**	**After completing the module, students** • Can design and implement electronic circuits for biosignal sensing • Can perform design steps (e.g. CAD design, circuit prototyping, communication protocol implementation etc.) while working in a team • Can perform a literature research • Can produce a written report in accordance with scientific standards • Can give a scientific presentation about their assigned topic
7	**Prerequisites**	General knowledge of circuit design, communication protocols (e.g. Bluetooth, Wi-Fi) and / or CAD design would be useful.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Human-system Interfaces - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232 ·B. Sc. and M. Sc. Medizintechnik ·B. Sc. and M. Sc. Elektrotechnik –Elektronik – Informationstechnik ·B.Sc. and M. Sc. Computional Engineering ·B.Sc. and M. Sc. Mechincal Engineering B.Sc. and M. Sc. Mechatronics
10	**Method of examination**	Seminar achievement

		Written Report (5 - 10 pages), Project Presentation (30 minutes)
11	**Grading procedure**	Seminar achievement (100%) Written Report (60%) and Live Presentation (40%)
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**	Merletti, R., and G. L. Cerone. "Tutorial. Surface EMG detection, conditioning and pre-processing: Best practices." Journal of Electromyography and Kinesiology 54 (2020): 102440. DOI: https://doi.org/10.1016/j.jelekin.2020.102440 S. Koutsoftidis, D. Y. Barsakcioglu, K. Petkos, D. Farina and E. M. Drakakis, "Myolink: A 128-Channel, 18 nV/Hz−−−√, Embedded Recording System, Optimized for High-Density Surface Electromyogram Acquisition," in IEEE Transactions on Biomedical Engineering, vol. 69, no. 11, pp. 3389-3396, Nov. 2022, doi: 10.1109/TBME.2022.3170025. DOI: https://doi.org/10.1109/TBME.2022.3170025 G. L. Cerone, A. Botter, T. Vieira and M. Gazzoni, "Design and Characterization of a Textile Electrode System for the Detection of High-Density sEMG," in IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 29, pp. 1110-1119, 2021, doi: 10.1109/TNSRE.2021.3086860. DOI: https://doi.org/10.1109/TNSRE.2021.3086860

1	**Module name** 47591	**Seminar Cognitive Surgical Robotics**	**5 ECTS**
2	Courses / lectures	Hauptseminar: Seminar Cognitive Surgical Robotics (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Franziska Mathis-Ullrich	

4	**Module coordinator**	Prof. Dr. Franziska Mathis-Ullrich
5	**Contents**	In contrast to industrial robots, surgical robots cannot follow pre-programmed motions. In surgical applications, next-generation learning robots will need to continuously sense their environment through sensors, interpret this data to reason about the environment, and update their behaviour accordingly, informed by previously learned strategies. (i.e., machine learning and AI). In the style of the tradition sense-plan-act model of robot control, cognitive surgical robotics encompasses methods that: • enable surgical robots to process sensor information to a higher level of abstraction, • reason about their behaviour in the context of an environment state and task to solve, • plan actions, and • execute the planned actions in their environment. These methods have to take into account the particular challenges of surgical applications, such as interaction with deformable objects, challenging visuals (e.g. blood, reflections, occlusions, smoke, …), complex long duration tasks, and virtually no room for error recovery. During the seminar, students will conduct a thorough literature research for a specific topic provided. The research study includes finding, understanding, and summarizing the state of the art as well as a critical review and analysis concerning limitations and potential of various methods.
6	**Learning objectives and skills**	Students • learn methods to effectively execute a literature study and are provided with the basic rules to cite research papers in a scientific report. • independently research state-of-the-art literature on the topic of cognitive and cognition-guided robots in surgery. • analyse their findings and critically evaluate the potential and limitations thereof. • excerpt the essential findings from their literature search and analysis and summarize them according to the level of knowledge of the fellow students.
7	**Prerequisites**	General knowledge in the areas AI and robotics will be an advantage.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Human-system Interfaces - Seminar & Laboratory Master of Science Autonomy Technologies 20232

		Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Seminar achievement Presentation and written report. The students will give a scientific presentation in English according to international conference standards. Written report: 14 - 15 pages (on our template) Presentation: 10 min presentation and 10 min discussion of the topic Attendance at the seminar student colloquium
11	**Grading procedure**	Seminar achievement (100%) Report: 50%, Presentation: 50%
12	**Module frequency**	Every semester
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**	

Sensing & Perception - Seminar & laboratory

1	**Module name** 97651	**Laborpraktikum Image and Video Compression** Laborpraktikum Multimediakommunikation	**2,5 ECTS**
2	Courses / lectures	Praktikum: Lab Course Image and Video Compression (3 SWS) (WiSe 2026)	2,5 ECTS
3	Lecturers	Marc Windsheimer	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup
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 Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
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 for this semester!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module for this semester!	

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 language Python. The course consists of 5 guided experiments in which students work on programming problems in groups of two. The following topics are treated in theses sessions: • Digital signals and A/D conversion • The DFT and spectral analysis • Non-recursive filters and filter banks • Recursive filters • Adaptive filters. After the lab experiements, each group works has to complete an individual project from the field of digital signal processing.
6	**Learning objectives and skills**	The students • create Python programs for the each experiements and, by this, apply knowledge acquired in the DSP lecutre 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**	The course requires knowledge in Python programming and basic knowledge in digital signal processing. Attendance of the DSP lecture is strongly recommended but not mandatory.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Practical achievement The preparation, as well as the results of the past experiment will be examined by a short test at the beginning of each lab session. For passing the lab course, a minimum number of points from the tests and the project is required.
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**	english
16	**Bibliography**	Main references: 1. H. Löllmann: "Lecture Notes Digital Signal Processing", MultimediaCommunications and Signal Processing, FAU, 2025 2. A. V. Oppenheim, R.W. Schafer and J. R.Buck: "Discrete-Time SignalProcessing", 2nd edition, Prentice Hall, 1999. Further references are provided by the course material.

1	**Module name** 878210	**Lab course machine learning in signal processing**	**2,5 ECTS**
2	Courses / lectures	Praktikum: Lab Course Machine Learning in Signal Processing (4 SWS) (SoSe 2026)	2,5 ECTS
3	Lecturers	Marc Hölle Prof. Dr. Vasileios Belagiannis Rohan Asthana Michele De Vita Leonhard Kraft	

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 corse.
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**	Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
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) Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning. 2) Friedman, J., Hastie, T., & Tibshirani, R. (2001). The elements of statistical learning. 3) Raschka, S., Liu, Y. H., Mirjalili, V., & Dzhulgakov, D. (2022). Machine Learning with PyTorch and Scikit-Learn: Develop machine learning and deep learning models with Python.

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 for this semester!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module for this semester!	

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 Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
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** 97520	**Laborpraktikum Digitale Signalverarbeitung**	**2,5 ECTS**
2	Courses / lectures	Praktikum: Lab Course Digital Signal Processing (2 SWS) Attendance of the lab session is mandatory.	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Sebastian Schlecht Dr.-Ing. Heinrich Löllmann	

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 language Python. The course consists of 5 guided experiments in which students work on programming problems in groups of two. The following topics are treated in theses sessions: • Digital signals and A/D conversion • The DFT and spectral analysis • Non-recursive filters and filter banks • Recursive filters • Adaptive filters. After the lab experiements, each group works works on an individual project from the field of digital signal processing. To complete the project, the Python implementation of the assigned task and a short report (3-5 pages) about the project needs to be submitted.
6	**Learning objectives and skills**	The students • create Python programs for the each experiements and, by this, apply knowledge acquired in the DSP lecutre 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**	The course requires knowledge in Python programming and basic knowledge in digital signal processing. Attendance of the DSP lecture is strongly recommended but not mandatory.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Practical achievement The preparation, as well as the results of the past experiment will be examined by a short test at the beginning of each lab session. For

		passing the lab course, a minimum number of points from the tests and and sucessfull completion of the 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**	Main references: 1. H. Löllmann: "Lecture Notes Digital Signal Processing", MultimediaCommunications and Signal Processing, FAU, 2025 2. A. V. Oppenheim, R.W. Schafer and J. R.Buck: "Discrete-Time SignalProcessing", 2nd edition, Prentice Hall, 1999. Further references are provided by the script for this lab course (which is handed out at the introductory meeting.

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	Currently no teaching units are offered for this module. For further information on teaching units please contact the module managers.	
3	Lecturers		

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 Master of Science Autonomy Technologies 20232
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** 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 Prof. Dr. Vasileios Belagiannis Rohan Asthana Leonhard Kraft	

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 Master of Science Autonomy Technologies 20232
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** 92374	**Seminar on Selected Topics in Machine Learning**	**2,5 ECTS**
2	Courses / lectures	Seminar: Seminar on Selected Topics in Machine Learning (2 SWS) (SoSe 2026) Seminar: Seminar on Selected Topics in Machine Learning (2 SWS) (WiSe 2026) The participants must be present at all in-person events.	2,5 ECTS 2,5 ECTS
3	Lecturers	Marc Hölle Marc Hölle Prof. Dr. Vasileios Belagiannis Rohan Asthana Michele De Vita Leonhard Kraft	

4	**Module coordinator**	Prof. Dr. Vasileios Belagiannis
5	**Contents**	The students will study, understand, and present scientific publications from the literature on machine learning and deep learning. At the end of the seminar, the student will be able to summarise and present a publication. The seminar covers a wide range of research topics in the field of machine learning and deep learning, including generative and foundation models, different types of learning and applications machine learning.
6	**Learning objectives and skills**	The students will learn to: • Conduct literature reviews. • Present and analyse a scientific topic. • Write a report on a specific problem. • Discuss and communicate research findings.
7	**Prerequisites**	Basic knowledge in Machine Learning and Deep Learning beneficial
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Seminar achievement The assigned topic must be presented at the end of the seminar in a talk (15 to 20 minutes) and presented in a written report (5 to 10 pages).
11	**Grading procedure**	Seminar achievement (100%) For the final grade, the presentation is weighted at 80% and the submitted report at 20%.
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**	Literature research is one of the learning objectives of the seminar. In the event that more in-depth literature is required, this will be made available during the seminar.

1	**Module name** 97690	**Laborpraktikum Sensorik** Laboratory course: Sensor technology	**2,5 ECTS**
2	Courses / lectures	Praktikum: Sensorik-Praktikum (3 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Philipp Beckerle Matthias Voß Niklas Bünte	

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 Master of Science Autonomy Technologies 20232
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**	

1	**Module name** 47574	**Lab Course Machine Learning and Systems**	**2,5 ECTS**
2	Courses / lectures	Praktikum: Lab Course Machine Learning and Systems (4 SWS) It is mandatory to attend all sessions of the lab course.	2,5 ECTS
3	Lecturers	Leonhard Kraft	

4	**Module coordinator**	Prof. Dr. Vasileios Belagiannis
5	**Contents**	The students will learn to develop machine learning algorithms for systems. Lab projects will focus on efficient model training and inference, hardware-aware algorithms, interpretability, and robustness of machine learning systems. Deep neural networks will be the main approach for development. The assignments will include tasks such as: • Neural network compression. • Machine learning algorithms on embedded devices. • Automated driving applications. • Generative models. • Model interpretability. Benchmarking.
6	**Learning objectives and skills**	The students will learn to: • Develop hardware-aware machine learning algorithms. • Implement neural network architectures for robotic perception. • Train and fine-tune deep neural network models. • Deploy and benchmark machine learning algorithms.
7	**Prerequisites**	Knowledge in Machine Learning
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Practical achievement The credit points will be awarded once the practical work has been passed. In particular: There is a lab course assignment almost every other week, conducted in Python. Details of each assignment are provided in the course material that has been distributed. Each assignment is prepared during the lab course session and at home. The tasks set for these assignments are normally programming-related and the deliverable is usually Python code.

		There is a deadline for submitting each assignment. Each assignment is then assessed. In order to pass the lab course, all assignments must be submitted and passed.
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**	english
16	**Bibliography**	• Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning. • Raschka, S., Liu, Y. H., Mirjalili, V., & Dzhulgakov, D. (2022). Machine Learning with PyTorch and Scikit-Learn: Develop machine learning and deep learning models with Python.

1	**Module name** 47537	**Seminar Wearable Devices for Sensing the Neural Control of Movement**	**5 ECTS**
2	Courses / lectures	Seminar: Seminar on Wearable Devices For Sensing the Neural Control of Movement (MyoDesign) (4 SWS)	5 ECTS
3	Lecturers	Vlad Cnejevici Mounir Shaib Prof. Dr. Alessandro Del Vecchio	

4	**Module coordinator**	Prof. Dr. Alessandro Del Vecchio
5	**Contents**	• Analysis of muscle sensing wearable devices (e.g. electromyography, force myography etc.) • Electronics, software and CAD design of a wearable system • Signal filtering, amplification, data communication protocol (e.g., Bluetooth, Wi-Fi) and housing design • Examples of muscle sensing devices on the market and in literature
6	**Learning objectives and skills**	**After completing the module, students** • Can design and implement electronic circuits for biosignal sensing • Can perform design steps (e.g. CAD design, circuit prototyping, communication protocol implementation etc.) while working in a team • Can perform a literature research • Can produce a written report in accordance with scientific standards • Can give a scientific presentation about their assigned topic
7	**Prerequisites**	General knowledge of circuit design, communication protocols (e.g. Bluetooth, Wi-Fi) and / or CAD design would be useful.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Human-system Interfaces - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232 ·B. Sc. and M. Sc. Medizintechnik ·B. Sc. and M. Sc. Elektrotechnik –Elektronik – Informationstechnik ·B.Sc. and M. Sc. Computional Engineering ·B.Sc. and M. Sc. Mechincal Engineering B.Sc. and M. Sc. Mechatronics
10	**Method of examination**	Seminar achievement

		Written Report (5 - 10 pages), Project Presentation (30 minutes)
11	**Grading procedure**	Seminar achievement (100%) Written Report (60%) and Live Presentation (40%)
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**	Merletti, R., and G. L. Cerone. "Tutorial. Surface EMG detection, conditioning and pre-processing: Best practices." Journal of Electromyography and Kinesiology 54 (2020): 102440. DOI: https://doi.org/10.1016/j.jelekin.2020.102440 S. Koutsoftidis, D. Y. Barsakcioglu, K. Petkos, D. Farina and E. M. Drakakis, "Myolink: A 128-Channel, 18 nV/Hz−−−√, Embedded Recording System, Optimized for High-Density Surface Electromyogram Acquisition," in IEEE Transactions on Biomedical Engineering, vol. 69, no. 11, pp. 3389-3396, Nov. 2022, doi: 10.1109/TBME.2022.3170025. DOI: https://doi.org/10.1109/TBME.2022.3170025 G. L. Cerone, A. Botter, T. Vieira and M. Gazzoni, "Design and Characterization of a Textile Electrode System for the Detection of High-Density sEMG," in IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 29, pp. 1110-1119, 2021, doi: 10.1109/TNSRE.2021.3086860. DOI: https://doi.org/10.1109/TNSRE.2021.3086860

1	**Module name** 47591	**Seminar Cognitive Surgical Robotics**	**5 ECTS**
2	Courses / lectures	Hauptseminar: Seminar Cognitive Surgical Robotics (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Franziska Mathis-Ullrich	

4	**Module coordinator**	Prof. Dr. Franziska Mathis-Ullrich
5	**Contents**	In contrast to industrial robots, surgical robots cannot follow pre-programmed motions. In surgical applications, next-generation learning robots will need to continuously sense their environment through sensors, interpret this data to reason about the environment, and update their behaviour accordingly, informed by previously learned strategies. (i.e., machine learning and AI). In the style of the tradition sense-plan-act model of robot control, cognitive surgical robotics encompasses methods that: • enable surgical robots to process sensor information to a higher level of abstraction, • reason about their behaviour in the context of an environment state and task to solve, • plan actions, and • execute the planned actions in their environment. These methods have to take into account the particular challenges of surgical applications, such as interaction with deformable objects, challenging visuals (e.g. blood, reflections, occlusions, smoke, …), complex long duration tasks, and virtually no room for error recovery. During the seminar, students will conduct a thorough literature research for a specific topic provided. The research study includes finding, understanding, and summarizing the state of the art as well as a critical review and analysis concerning limitations and potential of various methods.
6	**Learning objectives and skills**	Students • learn methods to effectively execute a literature study and are provided with the basic rules to cite research papers in a scientific report. • independently research state-of-the-art literature on the topic of cognitive and cognition-guided robots in surgery. • analyse their findings and critically evaluate the potential and limitations thereof. • excerpt the essential findings from their literature search and analysis and summarize them according to the level of knowledge of the fellow students.
7	**Prerequisites**	General knowledge in the areas AI and robotics will be an advantage.
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Human-system Interfaces - Seminar & Laboratory Master of Science Autonomy Technologies 20232

		Networking & Collaboration - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Seminar achievement Presentation and written report. The students will give a scientific presentation in English according to international conference standards. Written report: 14 - 15 pages (on our template) Presentation: 10 min presentation and 10 min discussion of the topic Attendance at the seminar student colloquium
11	**Grading procedure**	Seminar achievement (100%) Report: 50%, Presentation: 50%
12	**Module frequency**	Every semester
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**	