Friedrich-Alexander-Universität
Erlangen-Nürnberg

Module description

for the degree programme

Master of Science

Autonomy Technologies

(Version of examination regulation: 20232)

Table of contents

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

4	**Module coordinator**	
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**	no Integration in curriculum available!
9	**Module compatibility**	Pflichtmodul Master of Science Autonomy Technologies 20232
10	**Method of examination**	
11	**Grading procedure**	
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**	
16	**Bibliography**	

Human-system Interfaces - core modules

1	**Module name** 92345	**Human-centered mechatronics and robotics**	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Philipp Beckerle
5	**Contents**	• Human-oriented design methods • Biomechanics Motions, measurement, and analysis Biomechanical models • o Elastic actuators o Control methods Cognitive and physical human-robot interaction Empirical research methods o Research process and experiment design o 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** 645618	**Human Computer Interaction** Human computer interaction	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Björn Eskofier Madeleine Flaucher Wolfgang Mehringer Anastasiya Zakreuskaya
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**	Written examination Electronic exam (in presence), 90min
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**	

1	**Module name** 47616	**Intent Detection and Feedback**	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Claudio Castellini
5	**Contents**	• Introduction to the problems of intent detection and somatosensory feedback: motivation, taxonomy, historical background. • Intent detection: theory and philosophical issues; defining the problem and the ground truth; success metrics; signals for intent detection; sensors for intent detection; feature extraction; applications of machine learning to the problem. • Somatosensory feedback: theory and physiology; sensory substitution; embodiment and agency induced by it; modalities of actuation; practical issues and metrics of performance. • Intent detection and somatosensory feedback in prosthetics: usefulness, success and challenges. • Intent detection and somatosensory feedback in rehabilitation and exoskeletons: usefulness, success and challenges. • Intent detection and somatosensory feedback in gaming and non-reha fields.
6	**Learning objectives and skills**	Students who have followed the module • have a broad understanding of intent detection and somatosensory feedback, especially in the frame of Rehabilitation and Assistive Robotics • can conceive and design a research project in the related subfield of the subject • have knowledge about the clinical and industrial situation of intent detection and feedback, especially including the problems and challenges of each technique and method • can tackle previously unknown problems
7	**Prerequisites**	Recommended: basic maths, especially statistics; fundamentals of signal processing and machine learning; mid-level programming Python, C# or similar; fundamentals of experimental psychology
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Human-system Interfaces - core modules Master of Science Autonomy Technologies 20232
10	**Method of examination**	Variable (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**	• [2010] Control of Hand Prostheses Using Peripheral Information, S. Micera, J. Carpaneto and S. Raspopović. • [2012] Control of Upper Limb Prostheses: Terminology and Proportional Myoelectric ControlA Review, A. Fougner, Ø. Stavdahl, P. J. Kyberd, Y. G. Losier and P. A. Parker. • [2015] Michael R Tucker et al., Control strategies for active lower extremity prosthetics and orthotics: a review, JNER 12:1 • [2015] A survey of sensor fusion methods in wearable robotics, D. Novak and R. Riener • [2016] Incremental Learning of Muscle Synergies: From Calibration to Interaction, C. Castellini. • [2018] JA Spanias, AM Simon, SB Finucane, EJ Perreault and LJ Hargrove, Online adaptive neural control of a robotic lower limb prosthesis, J Neural Eng. 15(1) • [2020] Jacob Rosen and Peter Walker Ferguson (eds.), Wearable Robotics Systems and Applications, Academic Press Elsevier • [2021] Michele Xiloyannis, Ryan Alicea, Anna-Maria Georgarakis, Florian L. Haufe, Peter Wolf, Lorenzo Masia and Robert Riener, Soft robotic suits: State of the art, core technologies and open challenges, IEEE Transactions on Robotics

1	**Module name** 92359	**Robot mechanisms and user interfaces**	**5 ECTS**
2	Courses / lectures	Vorlesung: Robot mechanisms and user interfaces (2 SWS) Übung: UE RMI (2 SWS)	5 ECTS 5 ECTS
3	Lecturers	Prof. Dr.-Ing. Philipp Beckerle Mehmet Ege Cansev	

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)
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.

Human-system Interfaces - specialization module

1	**Module name** 47679	**Advanced Upper-Limb Prosthetics**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Upper-Limb Prosthetics This Semester ONLY ONLINE. All relevant material can be found on StudOn. (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Claudio Castellini	

4	**Module coordinator**	Prof. Dr. Claudio Castellini
5	**Contents**	• Introduction to upper-limb prosthetics (ULPs): background, motivation, body- vs. self-powered; state of the art • ULPs as robotic arms: challenges and open questions • Human-machine interfaces for ULPs • Sensor modalities: surface electromyography and more • Intent detection for ULPs: reliability, dexterity, pattern recognition, incrementality, interactive machine learning • Feedback and sensory substitution • Human-Machine Interaction in ULPs • Designing ULP experiments • The clinical perspective: impacting on the amputees everyday life In the exercises, problems will be solved by working out code.
6	**Learning objectives and skills**	Students who have followed the course • have a broad understanding of ULPs • can conceive and design an intent-detection + feedback system for ULPs, given a set of requirements / specifications • have knowledge about the clinical situation in the world of ULPs • can tackle previously unknown problems
7	**Prerequisites**	• 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
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**	• *[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. • *[2011]* |Electromyogram pattern recognition for control of powered upper-limb prostheses: State of the art and challenges for clinical use|, E. Scheme and K. Englehart. • *[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]* |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. • *[2019]* |Upper-limb active prosthetics: an overview|, C. Castellini.

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. Ramy Zeineldin	

4	**Module coordinator**	Prof. Dr. Franziska Mathis-Ullrich Prof. Dr.-Ing. Thomas Seel
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 medical robotic applications for AI methods and technologies • Perception in robotic surgery, rehabilitation robots and medical service robots • Motion planning in robotic surgery, rehabilitation robots and medical service robots • Adaptation and Learning in Human-Robotic Systems • Motion learning in robotic surgery, rehabilitation robots and medical service robots • Cognition in robotic surgery, rehabilitation robots and medical service robots • Application Example: Perception in a robotic surgery system • Application Example: Motor learning in a compliant upper-limb rehabilitation robot • Application Example: Locomotion in a medical service robot
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 linear dynamic systems or 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
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german
16	**Bibliography**	

1	**Module name** 816185	**Body Area Communications** Body area communications	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Body Area Communications (2 SWS)	2,5 ECTS
3	Lecturers	Benedict Scheiner	

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 • tudents 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
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	german or english
16	**Bibliography**	

1	**Module name** 44445	**Cognitive Neuroscience for AI Developers**	**5 ECTS**
2	Courses / lectures	Vorlesung: Cognitive Neuroscience for AI Developers (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Andreas Kist Dr. rer. nat. Patrick Krauß	

4	**Module coordinator**	
5	**Contents**	Neuroscience has played a key role in the history of artificial intelligence (AI), and has been an inspiration for building human-like AI, i.e. to design AI systems that emulate human intelligence. Neuroscience provides a vast number of methods to decipher the representational and computational principles of biological neural networks, which can in turn be used to understand artificial neural networks and help to solve the so called black box problem. This endeavour is called neuroscience 2.0 or machine behaviour. In addition, transferring design and processing principles from biology to computer science promises novel solutions for contemporary challenges in the field of machine learning. This research direction is called neuroscience-inspired artificial intelligence. The course will cover the most important works which provide the cornerstone knowledge to understand the biological foundations of cognition and AI, and applications in the areas of AI-based modelling of brain function, neuroscience-inspired AI and reverse-engineering of artificial neural networks.
6	**Learning objectives and skills**	The students • Explain the principles of neural information processing in the brain • compare and analyze methods from neuroscience to study neural networks • explain the neuroscientific underpinnings of artificial intelligence • explain principles and concepts of cognitive science • explain principles and concepts of neuroscience • compare and analyze machine learning methods to analyze neural data • explain approaches from deep learning to model brain function • discuss the commonalities of neuroscience and artificial intelligence • implement the presented methods in Python • explain concepts from cognitive neuroscience for the design of artificial intelligence systems
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

11	**Grading procedure**	Variable (100%)
12	**Module frequency**	every semester
13	**Workload in clock hours**	Contact hours: 90 h Independent study: 60 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Gazzaniga, Michael. Cognitive Neuroscience - The Biology of the Mind. W. W. Norton & Company, 2018. Ward, Jamie. The Student's Guide to Cognitive Neuroscience. Taylor & Francis Ltd., 2019. Bermúdez, José Luis. Cognitive Science: An Introduction to the Science of the Mind. Cambridge University Press, 2014. Friedenberg, Jay D., and Silverman, Gordon W. Cognitive Science: An Introduction to the Study of Mind. SAGE Publications, Inc., 2015. Gerstner, Wulfram, et al. Neuronal dynamics: From single neurons to networks and models of cognition. Cambridge University Press, 2014.

1	**Module name** 47623	**Human-Robot Co-Adaptation**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Human-Robot Co-Adaptation (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Claudio Castellini Dr.rer.nat. Sabine Thürauf	

4	**Module coordinator**	Prof. Dr. Claudio Castellini
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)
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** 96310	**Image and Video Compression** Image and video compression	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup
5	**Contents**	*Multi-Dimensional Sampling* Sampling theorem revisited, 2D sampling, spatiotemporal sampling, motion in 3D sampling *Entropy and Lossless Coding* Entropy and information, variable length codes, Huffman coding, unary coding, Golomb coding, arithmetic coding *Statistical Dependency* Joint entropy and statistical dependency, run-length coding, fax compression standards *Quantization* Rate distortion theory, scalar quantization, Lloyd-Max quantization, entropy coded scalar quantization, embedded quantization, adaptive quantization, vector quantization *Predictive Coding* Lossless predictive coding, optimum 2D linear prediction, JPEG-LS lossless compression standard, differential pulse code modulation (DPCM) *Transform Coding* Principle of transform coding, orthonormal transforms, Karhunen-Loève transform, discrete cosine transform, bit allocation, compression artifacts *Subband Coding* Principle of subband coding, perfect reconstruction property, discrete wavelet transform, bit allocation for subband coding *Visual Perception and Color* Anatomy of the human eye, sensitivity of the human eye, color spaces, color sampling formats *Image Coding Standards* JPEG and JPEG2000 *Interframe Coding* Interframe prediction, motion compensated prediction, motion estimation, motion compensated hybrid coding *Video Coding Standards* H.261, H.263, MPEG-1, MPEG-2 / H.262, H.264 / MPEG-4 AVC, H.265 / MPEG-H HEVC
6	**Learning objectives and skills**	Die Studierenden • veranschaulichen die mehrdimensionale Abtastung und den Einfluss darauf durch Bewegung im Videosignal • unterscheiden und bewerten verschiedene Verfahren zur verlustfreien Codierung von Bild- und Videodaten • verstehen und analysieren Verbundentropie und statistische Abhängigkeiten in Bild- und Videodaten

		• berechnen skalare und vektorielle Quantisierer nach unterschiedlichen Optimierungsvorgaben (minimaler mittlerer quadratischer Fehler, entropiecodiert, eingebetteter Quantisierer) • bestimmen und evaluieren optimale ein- und zwei-dimensionale lineare Prädiktoren • wenden Prädiktion und Quantisierung sinnvoll in einem gemeinsamen DPCM-System an • verstehen das Prinzip und die Effekte von Transformations- und Teilbandcodierung für Bilddaten einschließlich optimaler Bitzuteilungen • beschreiben die Grundzüge der menschlichen visuellen Wahrnehmung für Helligkeit und Farbe • analysieren Blockschaltbilder und Wirkungsweisen hybrider Coder und Decoder für Videosignale • kennen die maßgeblichen internationalen Standards aus ITU und MPEG zur Bild- und Videokompression. 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**	Modul Signale und Systeme II" und das Modul Nachrichtentechnische Systeme"
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)

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", Berlin: Springer-Verlag, 2004

1	**Module name** 92343	**Image, Video, and Multidimensional Signal Processing**	**5 ECTS**
2	Courses / lectures	Vorlesung: Bild-, Video- und mehrdimensionale Signalverarbeitung (2 SWS) Übung: Übung zu Bild-, Video- und mehrdimensionale Signalverarbeitung (SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Andre Kaup Andy Regensky	

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**	
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** 47617	**Rehabilitation and Assistive Robotics**	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Claudio Castellini
5	**Contents**	• Introduction to Rehabilitation and Assistive Robotics: motivation, taxonomy, historical background • Prosthetics: upper- and lower limb prosthetics; clinical, mechatronics and societal challenges; machine learning and intent detection applied to prosthetics; signals and sensors. • Exoskeletons and exo-suits: realms of application, mechatronic and ergonomic challenges; intent detection and feedback; clinical acceptance, feasibility and effectiveness.
6	**Learning objectives and skills**	Students who have followed the module • have a broad understanding of Rehabilitation and Assistive Robotics, the motivations, problems and challenges • can conceive and design a research project in the related subfield of the subject • have knowledge about the clinical and industrial situation in RAR • can tackle previously unknown problems
7	**Prerequisites**	Recommended: basic maths, especially statistics; fundamentals of signal processing and machine learning; mid-level programming (Python, C# or similar); fundamentals of experimental psychology
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Human-system Interfaces - specialization module Master of Science Autonomy Technologies 20232
10	**Method of examination**	Variable
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**	• [2002] Control of Multifunctional Prosthetic Hands by Processing the Electromyographic Signal, M. Zecca, S. Micera, M. C. Carrozza and P. Dario. • [2010] Control of Hand Prostheses Using Peripheral Information, S. Micera, J. Carpaneto and S. Raspopović. • [2012] Control of Upper Limb Prostheses: Terminology and Proportional Myoelectric ControlA Review, A. Fougner, Ø. 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** 96880	**Speech Enhancement** Speech enhancement	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Speech Enhancement (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Emanuël Habets	

4	**Module coordinator**	Prof. Dr. Emanuël Habets
5	**Contents**	**Description** We live in a noisy world! In all applications related to speech, from hands-free communication to human-machine interfaces, a speech signal of interest captured by one or more microphones is contaminated by noise and reverberation. The quality and intelligibility of the signal of interest depend highly on the level of noise and reverberation. Therefore, it is highly desirable, and sometimes even indispensable, to "clean up" the captured signals before storage, transmission, or reproduction. This course discusses both model-driven and data-driven methods to estimate the signal of interest and aims to provide a strong foundation for researchers, engineers, and graduate students interested in signal and speech enhancement. **Relation to other courses** This course is the most advanced course offered by the university on this topic and serves as an excellent basis from which to commence research in the area. Various aspects of the course bring students up to date with the very latest developments in the field, as seen in recent international conferences and journals. This course is well complimented by |Selected Topics in Perceptual Audio Coding| (Prof. Herre) and |Auditory Models| (Prof. Edler).
6	**Learning objectives and skills**	• Formulate the speech enhancement problem mathematically. • Derive optimal single- and multi-channel filters to reduce noise and reverberation. • Evaluate and compare the performance of single- and multi-channel filters for speech enhancement. • Understand how reference signals and other prior information can be used in a speech enhancement system. • Understand the limitations and challenges of existing speech enhancement systems. • Understand the importance of binaural cues and the influence of a speech enhancement system on the binaural cues in the context of hearing aids. • Design a microphone array and analyze its performance. • Design a speech enhancement system for a given acoustic scenario. • Evaluate subjectively and objectively the performance of a speech enhancement system in terms of speech quality and intelligibility.

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

Human-system Interfaces - Seminar & Laboratory

1	**Module name** 92508	**Hauptseminar Cognitive Science in Engineering**	**2,5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Philipp Beckerle Dr. Chenxu Hao
5	**Contents**	In the seminar, students will analyze, present. and discuss recent research topics in Cognitve Science and Engineering. 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 Cognitive Science in Engineering. 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
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	only in summer semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 92507	**Laborpraktikum Human-Robot Interaction**	**2,5 ECTS**
2	Courses / lectures	Praktikum: Human-Robot Interaction Laboratory (2 SWS)	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**	
11	**Grading procedure**	
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**	**2,5 ECTS**
2	Courses / lectures	Seminar: Seminar Autonomous Systems and Mechatronics (2 SWS)	2,5 ECTS
3	Lecturers	Rodrigo Jose Velasco Guillen Prof. Dr.-Ing. Philipp Beckerle	

4	**Module coordinator**	Prof. Dr.-Ing. Philipp Beckerle
5	**Contents**	In the seminar, students will analyze, present. and discuss recent research topics in autonomous systems and mechatronics. This will comprise mechatronic component, system, and control design as well as advanced methods aiming at autonomous operation. Besides reflecting contemporary literature, the students are asked to conclude and suggest directions for future research.
6	**Learning objectives and skills**	On successful completion of this module, students will be able to comprehend and convey recent research challenges in the area of autonomous system and mechatronics. Moreover, they are prepared to infer future research lines from recent developments.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Human-system Interfaces - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	Seminar achievement
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**	**2,5 ECTS**
2	Courses / lectures	Seminar: Seminar Mensch-Roboter-Interaktion (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Philipp Beckerle	

4	**Module coordinator**	Prof. Dr.-Ing. Philipp Beckerle
5	**Contents**	In the seminar, students will analyze, present, and discuss recent research topics in 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
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.

Networking & Collaboration - core modules

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

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

		• vergleichen verschiedene Entzerrungsverfahren hinsichtlich deren Leistungsfähigkeit und Komplexität, • entwerfen einfache digitale Übertragungssysteme mit vorgeschriebenen Leistungs- und Bandbreiteneffizienzen sowie Spitzenwertfaktoren. • -- The students • analyze and classify digital modulation techniques in terms of performance and bandwidth efficiency as well as crest factor, • determine necessary criteria to design impulses for interference-free transmission, • characterize digital modulation methods in signal space, • determine information loss-free demodulation methods, • design optimal coherent and incoherent detection and decoding methods, • compare different equalization methods in terms of performance and complexity, • design simple digital transmission systems with prescribed power and bandwidth efficiency and crest factor.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 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	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 (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**	english
16	**Bibliography**	MacKay, D.: Information Theory, Inference, and Learning Algorithms, Cambridge University Press, Cambridge, 2003.

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 Nikita Shanin	

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
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** 96300	**MIMO Communication Systems** MIMO communication systems	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Robert Schober
5	**Contents**	Modern communication systems employ multiple antennas at the transmitter and/or receiver creating a multiple-input multiple-output (MIMO) system. This course covers the fundamental mathematical and communication theoretical concepts necessary for the design and analysis of MIMO communication systems. Relevant topics include MIMO Channel Capacity, Receive Diversity, Transmit Diversity, Space-Time Coding, Spatial Multiplexing, MIMO Transceiver Design, Multi-user MIMO, Massive MIMO, Relay-based MIMO, and applications in modern communication systems.
6	**Learning objectives and skills**	The students • learn about different MIMO channel models, • analyze MIMO communication systems with respect to their channel capacity and reliability, • determine MIMO figures of merit such as coding gain, diversity gain, and multiplexing gain, • compare and evaluate different MIMO receiver designs, • characterize the rate region of multiuser systems, • analyze massive MIMO systems, • discuss the advantages and disadvantages of different relay network architectures. Die Studierenden • lernen verschiedene MIMO-Kanalmodelle kennen, • analysieren MIMO-Kommunikationssysteme hinsichtlich der Kanalkapazität und Zuverlässigkeit, • ermitteln MIMO-Kenngrößen wie Codierungsgewinn, Diversitätsgewinn und Multiplexgewinn, • vergleichen und beurteilen verschiedene MIMO-Empfangsstrategien, • charakterisieren die Ratenregion von Mehrteilnehmersystemen, • analysieren Massive-MIMO-Systeme, • diskutieren die Vor- und Nachteile verschiedener Relaisnetzwerkarchitekturen.
7	**Prerequisites**	Basic course in communications
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Networking & Collaboration - core modules Master of Science Autonomy Technologies 20232
10	**Method of examination**	Written or oral
11	**Grading procedure**	Written or oral (100%)

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

Networking & Collaboration - specialization module

1	**Module name** 151664	**Advanced Communication Networks** Advanced communication networks	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

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

		• Classical resource allocation techniques: Centralized and distributed power control based on the Perron-Frobenius theorem. • Fundamentals of convex constrained optimization and application to resource allocation. • Resource allocation and fairness. • Fundamentals of nonconvex optimization and relaxation techniques. • Applications of nonconvex optimization to resource allocation. • Fundamentals of distributed optimization and applications to resource allocation. • Fundamental concepts of game theory. • Resource contention via game theoretical methods.
6	**Learning objectives and skills**	The student • Describes and/or recognizes wireless channel models. • Criticizes the limits of a layered architecture in wireless systems. • Defends the use of cross-layer design in wireless network. • Appraises and compares the distribution of functionalities in network entities for different architectures. • Argue on the pros and contras of different multiple access schemes according to various criteria (e.g. spectral efficiency, power efficiency, robustness to interference). • Compares and contrasts micro-diversity and various macro-diversity schemes. • Computes the total rate of SDMA with various receivers. • Relates the multiple access in uplink to broadcasting in downlink and justifies the concept of uplink-downlink duality. • Uses uplink-downlink duality to design a precoder and allocate power. • Contrasts multiple access in uplink and broadcasting in downlink in terms of channel state acquisition both for TDD and FDD transmission. • Uses multiuser diversity for opportunistic scheduling. • Compares multiuser diversity for users having identical and different channel statistics. • Contrasts opportunistic scheduling in terms of channel state acquisition and feedback both for uplink and downlink and for both FDD and TDD transmission schemes. • Appraises the impact of multiple antennas on opportunistic scheduling. • Analyses different settings with interference in small cells and designs countermeasures. • Categorizes relaying schemes in LTE. • Analyses performance of relaying schemes. • Argues on possible improvements of relaying schemes via network coding and physical layer network coding. • Uses the Perron-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)
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** 965820	**Approximate Computing** Approximate computing	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Joachim Falk Prof. Dr. Oliver Keszöcze 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**	Oral
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**	Weitere Informationen: https://www.cs12.tf.fau.de/lehre/lehrveranstaltungen/vorlesungen/approximate-computing

1	**Module name** 412023	**Channel Coding on Graphs** Channel coding on graphs	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

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

6	**Learning objectives and skills**	The student Uses idealized channel models (the binary symmetric channel (BSC), the binary erasure channel (BEC), the constrained-input Gaussian channel) to compute their capacities Contrasts soft output decoders with disjoint detection and decoding, maximum likelihood and maximum a posteriori decoders Relates the concepts of Parity Check, Hamming distance, weight enumerating functions to the performance analysis of codes on graphs Devises factor graphs of proposed communication systems Assesses and justifies the applicability of belief propagation to given factor graphs Assesses and justifies the applicability of message passing to codebooks defined in terms of Tanner graph or parity check matrix Applies message passing to codebooks defined in terms of Tanner graph or parity check matrix Analyses the performance of LDPC code decoding via density evolution Computes exit charts for LDPC codes for the equations of the density evolution Designs LDPC ensemble for a given channel to maximize the code rate Justifies the design of LDPC codes via design of LDPC ensembles Interprets convolutional codes as linear block codes Compares algebraic and dynamic representations of convolutional codes Computes steps of the Viterbi algorithm Summarizes and justifies the fundamental structure of the Viterbi algorithm Computes steps of the BCJR algorithm Summarizes and justifies the fundamental structure of BCJR algorithm Compares Viterbi and BCJR algorithms Justifies low complexity and/or practical implementations of the Viterbi and the BCJR algorithm Attaches a direct graph to a convolutional code and computes its transfer function Assesses the performance of the Viterbi decoder via (bit) weight enumerating function based on the transfer function method Interprets a BCJR algorithm as message passing over a factor graph Combines encoders of convolutional codes to generate parallel concatenated codes with interleaver (turbo codes) of given rate Combines encoders of convolutional codes to generate serial concatenated codes with interleaver (turbo codes) Compares the key features of parallel concatenated codes with interleaver (turbo codes) to serial concatenated codes with interleaver (turbo codes) Designs decoders for turbo codes utilizing coupled BCJR-based decoders for convolutional codes Interprets turbo decoders as factor graphs and justifies their implementation via message passing Assesses the performance of turbo codes using exit charts

		Formulates the concept of source polarization and relates it to polar channel coding Interprets polar channel coding as factor graphs Designs polar channel codes Argues about capacity achievability of polar channel codes
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Networking & Collaboration - specialization module 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**	

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

4	**Module coordinator**	Arslan Ali Prof. Dr.-Ing. Georg Fischer Prof. Dr.-Ing. Norman Franchi
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** 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	Adela Vagollari 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
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** 636348	**Cyber-Physical Systems** Cyber-physical systems	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Dr.-Ing. Torsten Klie
5	**Contents**	Klassische Computersysteme zeichnen sich durch eine strikte Trennung von realer und virtueller Welt aus. Moderne Steuerungssysteme, die z.B. in modernen Fahrzeugen verbaut sind und die aus einer Vielzahl von Sensoren und Aktoren bestehen, entsprechen diesem Bild nur sehr eingeschränkt. Diese Systeme, oft "Cyber-Physical Systems (CPS)" genannt, erkennen ihre physische Umgebung, verarbeiten diese Informationen und können die physische Umwelt auch koordiniert beeinflussen. Hierzu ist eine starke Kopplung von physischem Anwendungsmodell und dem Computer-Steuerungsmodell nötig. Im Unterschied zu Eingebetteten Systemen bestehen CPS meist aus vielen vernetzten Komponenten, die sich selbständig untereinander koordinieren. Diese Vorlesung spannt den Bogen von kontrolltheoretischen Grundlagen über 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** 96310	**Image and Video Compression** Image and video compression	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup
5	**Contents**	*Multi-Dimensional Sampling* Sampling theorem revisited, 2D sampling, spatiotemporal sampling, motion in 3D sampling *Entropy and Lossless Coding* Entropy and information, variable length codes, Huffman coding, unary coding, Golomb coding, arithmetic coding *Statistical Dependency* Joint entropy and statistical dependency, run-length coding, fax compression standards *Quantization* Rate distortion theory, scalar quantization, Lloyd-Max quantization, entropy coded scalar quantization, embedded quantization, adaptive quantization, vector quantization *Predictive Coding* Lossless predictive coding, optimum 2D linear prediction, JPEG-LS lossless compression standard, differential pulse code modulation (DPCM) *Transform Coding* Principle of transform coding, orthonormal transforms, Karhunen-Loève transform, discrete cosine transform, bit allocation, compression artifacts *Subband Coding* Principle of subband coding, perfect reconstruction property, discrete wavelet transform, bit allocation for subband coding *Visual Perception and Color* Anatomy of the human eye, sensitivity of the human eye, color spaces, color sampling formats *Image Coding Standards* JPEG and JPEG2000 *Interframe Coding* Interframe prediction, motion compensated prediction, motion estimation, motion compensated hybrid coding *Video Coding Standards* H.261, H.263, MPEG-1, MPEG-2 / H.262, H.264 / MPEG-4 AVC, H.265 / MPEG-H HEVC
6	**Learning objectives and skills**	Die Studierenden • veranschaulichen die mehrdimensionale Abtastung und den Einfluss darauf durch Bewegung im Videosignal • unterscheiden und bewerten verschiedene Verfahren zur verlustfreien Codierung von Bild- und Videodaten • verstehen und analysieren Verbundentropie und statistische Abhängigkeiten in Bild- und Videodaten

		• berechnen skalare und vektorielle Quantisierer nach unterschiedlichen Optimierungsvorgaben (minimaler mittlerer quadratischer Fehler, entropiecodiert, eingebetteter Quantisierer) • bestimmen und evaluieren optimale ein- und zwei-dimensionale lineare Prädiktoren • wenden Prädiktion und Quantisierung sinnvoll in einem gemeinsamen DPCM-System an • verstehen das Prinzip und die Effekte von Transformations- und Teilbandcodierung für Bilddaten einschließlich optimaler Bitzuteilungen • beschreiben die Grundzüge der menschlichen visuellen Wahrnehmung für Helligkeit und Farbe • analysieren Blockschaltbilder und Wirkungsweisen hybrider Coder und Decoder für Videosignale • kennen die maßgeblichen internationalen Standards aus ITU und MPEG zur Bild- und Videokompression. 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**	Modul Signale und Systeme II" und das Modul Nachrichtentechnische Systeme"
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)

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", Berlin: Springer-Verlag, 2004

1	**Module name** 43141	**Mobile Communications** Mobile communications	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Ralf Müller
5	**Contents**	History of mobile communications, cellular systems, sectorization, spectral efficiency, co-channel interference, adjacent-channel interference, near-far effect, cellular network architecture, antenna types and parameters, free space propagation, reflection, attenuation, diffraction, scattering, classification of channel models, ground reflection model, Okumura-Hata model, shadowing, narrow-band fading, time- variant channels, scattering function, delay-Doppler spectrum, diversity principles, combining methods, diversity gain, multiplexing, duplexing, digital modulation, Gaussian filtered minimum shift keying, basics of channel coding, interleaving, global system for mobile communications, physical versus logical channels, frame structure, call set-up, synchronization, channel estimation, hand-off
6	**Learning objectives and skills**	The students explain the cellular structure of mobile communication systems. They students explain the physical mechanics of radio wave propagation in the cm-band. The students explain the GSM cellular communications standard. The students discuss the pros and cons of several multiple-access and duplexing methods. The students discuss the pros and cons of several modulation and coding formats. The students decide which antenna type is suitable for a given morphological structure of the environment. The students predict the amplitude and dynamic of the 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	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
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english

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

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

4	**Module coordinator**	Prof. Dr.-Ing. Ralf Müller
5	**Contents**	Dual antenna arrays, compressive sensing, Wishart distribution, factor iid model, Kronecker model, convergence of random variables, semi-circle law, quarter circle law, full circle law, Haar distribution, Marchenko-Pastur distribution, Stieltjes transform, Girkos law, unitary invariance, freeness, free convolution, R-transform, free central limit theorem, free Poisson limit theorem, subordination, S-transform, R-diagonal random matrices, R-diagonal free convolution, Haagerup-Larsen law, operator-valued freeness, linearization of noncommutative polynomials, free Fourier transform, self-averaging properties, microscopic vs. macroscopic random variables, quenched random variable, a statistical physics point of view of digital systems, spin glasses, frozen disorder, replica method, replica continuity, replica symmetry, replica symmetry breaking, approximate message passing, classification of np-complete problems
6	**Learning objectives and skills**	The students find the limiting eigenvalue distributions of various types of random matrices. The students explain Stieltjes, R- and S-transforms. The students explain the limits of various types of fading channels. The students design coding and decoding methods for a given type of multiuser channel. The students perform additive and multiplicative free convolution. The students calculate the asymptotic eigenvalues distributions of given random matrix ensembles. The students construct random matrix ensembles with a given eigenvalue distribution. The students linearize matrix polynomials. The students derive the Boltzmann distribution. The students utilize saddle point integration. The students perform replica calculations. The students explain the meaning of replica symmetry breaking. The students collaborate on solving exercise problems.
7	**Prerequisites**	Recommended: Good skills in linear algebra, probability theory and complex analysis
8	**Integration in curriculum**	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: 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** 43420	**Transmission and Detection for Advanced Mobile Communications** Transmission and detection for advanced mobile communications	**2,5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

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
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

Networking & Collaboration - Seminar & Laboratory

1	**Module name** 293179	**Praktikum Digitale Übertragung** Digital communications 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**	Dr.-Ing. Clemens Stierstorfer
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**	• Es sind 5 Versuche zu absolvieren. Diese sind in den Kursunterlagen beschrieben. • Jeder Versuch ist zu Hause schriftlich vorzubereiten. Die Vorbereitung wird zu Beginn eines jeden Versuch überprüft

		und bewertet (ausreichend/nicht ausreichend). Die schriftliche Vorbereitung ist vor Beginn des Versuchs zusätzlich auf StudOn elektronisch einzureichen. • 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. Zusätzlich sind erstellte Dateien und Unterlagen in Anschluss an die Versuchsdurchführung elektronisch auf StudOn zu hinterlegen. • Zum Bestehen des Praktikums sind 5 ausreichende Versuchsvorbereitungen und 5 ausreichende Versuchsdurchführungen notwendig. • Das erfolgreiche Absolvieren einführender Unterweisungen und Aufgaben in die verwendeten Geräte, die Matlab-Entwicklungsumgebung sowie die Lernplattform StudOn ist Voraussetzung für die weitere Teilnahme am Praktikum. • There are 5 experiments to be completed. These are described in the course documentation. Each experiment must be prepared in writing at home. The preparation is checked and evaluated at the beginning of each attempt (sufficient/ not sufficient). The written preparation must also be submitted electronically on StudOn prior to the start of the attempt. • 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. In addition, the files and documents created are to be stored electronically on StudOn following the execution of the experiment. • To pass the lab course, 5 sufficient experiment preparations and 5 sufficient experiment executions are required. • Successful completion of introductory instruction and assignments in the equipment used, the Matlab development environment and the StudOn learning platform is a prerequisite for further participation in the lab course. ----
11	**Grading procedure**	
12	**Module frequency**	every 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 • Skriptum zur Vorlesung Digitale Übertragung bzw. Digital Communications

		• übliche Standardlehrwerke zur Thematik (Proakis, Haykin usw.)

1	**Module name** 92527	**Joint communications and sensing in wireless systems**	**2,5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Norman Franchi
5	**Contents**	Radio sensing as an integrated capability of mobile communication networks have been identified as one of the key features of future 6G cellular systems. The main challenge here lies in the joint design of sensing and communications because mobile communications and radar, for example, are still designed as more or less independent technologies and systems with different design approaches. But, especially, the convergence of both technologies is of utmost interest, enabling benefits of integrated radio sensing like • sensing/radar-as-a-service, e.g., for object and obstacle detection, • joint signal processing frameworks for both target/environment detection/analysis and wireless communications, • highly synchronous operation of both technologies, • balancing dual-functional performance (coordination gain), • performing mutual assistance, • increasing resource efficiency using shared radio resources, • jamming detection and mitigation, • optimization of the network performance based on collected sensing information.
6	**Learning objectives and skills**	The design of JC&S-based wireless systems faces challenges in several electrical engineering areas, especially electronics design, radio-frequency (RF) design, information and communications technology (ICT) design, and system design. The seminar will examine the latest approaches, developments, and findings from research in the field of JC&S and Integrated Sensing and Communication (ISAC), respectively. And topics are offered across all of the aforementioned disciplines. Participants in this seminar are expected to have a basic knowledge of communications systems, such as those acquired in the Digital Communications and Fundamentals of Mobile Communications lectures.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Networking & Collaboration - Seminar & Laboratory 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** 97651	**Laborpraktikum Image and Video Compression** Laborpraktikum Multimediakommunikation	**2,5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Dr.-Ing. Christian Herglotz
5	**Contents**	• Einführung in die Programmierumgebung MATLAB • Realisierung der Verarbeitungsblöcke von Videocodern • Aufbau eines Videocodecs und optionale Erweiterungen • Durchführung eines subjektiven Vergleichs verschiedener Videocodecs • Präsentation und kritische Beurteilung der Ergebnisse *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**	Die Studierenden • erzeugen ein funktionsfähiges Programmsystem mit der Programmierumgebung MATLAB, • beurteilen die Funktionsblöcke von Video-Codern, • gestalten ihren eigenen Videocodec und entwickeln dazu von ihnen selbst gewählte optionale Erweiterungen, • bewerten die von ihnen realisierten Videocodecs durch einen subjektiven Vergleich, • reflektieren den Lernprozess während des Praktikums. * Learning Targets 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**	Das Praktikum Image and Video Compression wendet sich an Studierende aus den Studiengängen EEI, IuK und CE, die die Vorlesung Bild- und Videocodierung (Image and Video Coding) im gleichen Semester hören oder bereits gehört haben. The lab course Image and Video Compression is suited for students from the field of study in EEI, IuK, WIng, ASC, CME, and CE, who participate in the lecture Image and Video Compression in the current summer semester or who have already attended the lecture.
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**	
11	**Grading procedure**	
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**	Das Skriptum Praktikum Image and Video Compression wird in der Einführungsveranstaltung ausgegeben. The lab course notes will be distributed during the introductory meeting.

Planning & Control - core modules

1	**Module name** 43405	**Introduction to Deep Learning**	**5 ECTS**
2	Courses / lectures	Vorlesung: Introduction to Deep Learning (SWS) Übung: Supplements for Introduction to Deep Learning (SWS)	- -
3	Lecturers	Prof. Dr. Vasileios Belagiannis Youssef Dawoud	

4	**Module coordinator**	
5	**Contents**	Bei der digitalen Übertragung spielen Kanalverzerrungen aufgrund ständig steigender Datenraten eine immer grössere Rolle. Bei vielen Anwendungen müssen für eine zuverlässige Übertragung komplexe Entzerrverfahren eingesetzt werden. Dies gilt sowohl für die leitungsgebundene als auch die drahtlose Kommunikation. Z.B. werden in der xDSL-Systemfamilie (Digital Subscriber Lines), die eine schnelle digitale Übertragung über Ortsanschlussleitungen gewährleistet, oft entscheidungsrückgekoppelte Entzerrverfahren oder Vorcodierungsverfahren eingesetzt und beim Mobilfunkstandard GSM und seiner Weiterentwicklung EDGE (Enhanced Data Rates for GSM Evolution) Maximum-Likelihood-Sequenzschätzung bzw. zustandsreduzierte Entzerrung. Eng im Zusammenhang mit der eigentlichen Entzerrung stehen Adaptionsverfahren, mit denen die Parameter des Entzerrers optimal an den Übertragungskanal angepasst werden können. Lernziel: Ziel der Vorlesung ist eine umfassende Darstellung gebräuchlicher Entzerrungs- und Adaptionsverfahren. Den Teilnehmern sollen fundierte Kenntnisse der verschiedenen Verfahren vermittelt werden, die sie zu deren sinnvollem Einsatz in der Praxis befähigen. Content: Channel distortions are playing an increasingly important role in digital transmission due to constantly increasing data rates. In many applications, complex equalization techniques must be used for a reliable transmission. This applies to both wired and wireless communication. For example, decision feedback equalization or precoding techniques are often used in the xDSL (Digital Subscriber Lines) system family, which ensures fast digital transmission over local subscriber loops, and the GSM system and its advanced version EDGE (Enhanced Data Rates for GSM Evolution) employ maximum likelihood sequence estimation and state-reduced equalization. Closely related to the task of equalization are adaptation methods with which the parameters of the equalizer can be optimally adjusted to the transmission channel. Objective: The aim of the lecture is a comprehensive presentation of common equalization and adaptation methods. The participants should acquire an in-depth knowledge of the various procedures which enables them to make meaningful design decisions in practice.

6	**Learning objectives and skills**	Die Studierenden • beschreiben verschiedene Verfahren zur Entzerrung frequenzselektiver Übertragungskanäle wie lineare Entzerrung, entscheidungsrückgekoppelte Entzerrung und Maximum-Likelihood-Sequenzschätzung, • setzen die verschiedenen Ansätze in Blockdiagramme um und optimieren deren Komponenten, • vergleichen Entzerrverfahren hinsichtlich ihrer Leistungsfähigkeit, charakterisiert durch die Fehlerrate, und Komplexität, • wählen geeignete Verfahren für verschiedene Anwendungen wie leitungsgebundene und drahtlose Übertragung aus, • entwerfen neuartige Verfahren für gegebene Anforderungen, • formulieren Adaptionsalgorithmen zur automatischen Anpassung des Empfängers eines Übertragungssystems an den Kanal, • ordnen Entzerrverfahren einen geeigneten Adaptionsalgorithmus zu. Learning Objectives and Competences: The students - describe various methods for equalizing frequency-selective transmission channels such as linear equalization, decision feedback equalization and maximum likelihood sequence estimation, - realize various approaches in block diagrams and optimize their components, - compare equalization methods in terms of their performance, characterized by the error rate, and complexity, - select suitable methods for various applications such as wired and wireless transmission, - design novel schemes for given requirements, - formulate adaptation algorithms for automatic adaptation of the receiver of a transmission system to the channel, - assign suitable adaptation algorithms to equalization schemes.
7	**Prerequisites**	Vorkenntnisse in Systemtheorie und digitaler Signalverarbeitung, sowie entweder der Vorlesung Nachrichtentechnische Systeme oder Digitale Übertragung sind für die Teilnahme hilfreich.
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**	every semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	
16	**Bibliography**	Gerstacker, W.: Skriptum zur Vorlesung Entzerrung und adaptive Systeme in der digitalen Übertragung. Huber, J.: Trelliscodierung, Springer Verlag, Berlin, 1992. Benedetto, S., Biglieri, E.: Principles of Digital Transmission with Wireless Applications, Kluwer Academic Publishers, New York, 1999. Proakis, J. G.: Digital Communications. McGraw-Hill, New York, 3. ed., 1995. Haykin, S.: Adaptive Filter Theory, Prentice Hall, Upper Saddle River, NJ, 3. ed., 1996.

1	**Module name** 92529	**Nonlinear Control Systems**	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Knut Graichen
5	**Contents**	Many control problems are nonlinear by nature. Classical control methods are based on linear approximations or a linearization of these systems in the neighborhood of setpoints to be controlled. In contrast to linear control theory, this module focuses on advanced nonlinear methods for the analysis and control of nonlinear systems by exploiting structural properties. In summary, the course covers the following topics: • Examples of nonlinear physical systems and nonlinear phenomena • Introduction to computer algebra software • Analysis of nonlinear systems • Stability of nonlinear systems (Lyapunov stability) • Lyapunov-based control design (Backstepping) • Reachability/controllability and observability of nonlinear systems • Exact linearization via feedback • Differential flatness of nonlinear systems • Flatness-based feedforward and feedback control of nonlinear systems
6	**Learning objectives and skills**	After successful completion of the module, students will be able to • describe and analyze nonlinear systems • determine the input/output behavior of nonlinear systems • design nonlinear state feedback controllers via exact input-output and input-state linearization • apply the concept of differential flatness for the feedforward feedback control of nonlinear systems • use computer algebra software for the analysis and control design of nonlinear systems
7	**Prerequisites**	Basic knowledge of advanced mathematics Linear control theory (state space methods), e.g. "Regelungstechnik B"
8	**Integration in curriculum**	semester: 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**	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Knut Graichen
5	**Contents**	Many problems in economy and industry require an optimal solution under consideration of specific criteria and constraints. From a mathematical point of view, this requires the numerical solution of a parametric optimization problem or a dynamic optimization problem. The latter formulation accounts for the dynamics of the underlying process and is particularly relevant in the context of optimal control and model predictive control (MPC). In summary, the course covers the following topics: • Introduction to and examples of static and dynamic optimization problems • Unconstrained numerical optimization (optimality conditions, numerical methods) • Constrained numerical optimization (linear/quadratic/nonlinear problems, optimality conditions, numerical methods) • Dynamical optimization / optimal control problems (calculus of variations, optimality conditions, PMP, numerical methods) • Nonlinear model predictive control (formulations, stability, real-time solution)
6	**Learning objectives and skills**	After successful completion of the module, students will be able to • differentiate the problem classes of parametric and dynamic optimization • formulate and analyze practical optimization problems • derive and solve the optimality conditions for unconstrained and constrained optimization problems using state-of-the-art software tools • classify the different formulations and stability criteria for nonlinear model predictive control • design a model predictive controller for a given control task and analyze the performance and stability properties in closed loop • realize and implement a real-time MPC for highly dynamical nonlinear systems with sampling times in the (sub)millisecond range using modern state-of-the-art (N)MPC software
7	**Prerequisites**	Basic knowledge of advanced mathematics (especially linear algebra) Basic knowledge of dynamical systems in time domain description (e.g. Regelungstechnik B)
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Planning & Control - core modules Master of Science Autonomy Technologies 20232
10	**Method of examination**	Written examination (60 minutes)

11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	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** 92519	**Robotics 1**	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Knut Graichen Dr.-Ing. Andreas Völz
5	**Contents**	This lecture introduces the fundamentals of robotics with a focus on manipulator control. The course covers the following topics: • Modeling: coordinate systems and transformations, parameterization of rotation matrices, forward and inverse kinematics, Jacobians and singularities • Trajectory planning: polynomial and trapezoidal trajectories, trajectories with intermediate points, trajectories in task space • Linear control: actuator dynamics, decentralized motion control, basics of task space and force control
6	**Learning objectives and skills**	After successful completion of the module, students will be able to • mathematically describe and analyze the kinematics of robotic manipulators. • plan trajectories for robot motions. • design and implement linear methods for robot motion and force control.
7	**Prerequisites**	• Basis knowledge of advanced mathematics • Basic knowledge of control theory
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Planning & Control - core modules Master of Science Autonomy Technologies 20232
10	**Method of examination**	Written examination
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.

Planning & Control - specialization module

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		

4	**Module coordinator**	Prof. Dr.-Ing. Knut Graichen
5	**Contents**	Die Vorlesung 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 der Vorlesung 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**	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)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german
16	**Bibliography**	• C.T. Chen. Control System Design, Pond Woods Press, 1987 • O. Föllinger. Regelungstechnik: Einführung in die Methoden und ihre Anwendung. 8. Auflage, Hüthig, 1994 • H. Geering. Regelungstechnik, 6. Auflage, Springer, 2004 • T. Kailath. Linear Systems, Prentice Hall, 1980 • G. Ludyk. Theoretische Regelungstechnik 1, Springer, 1995 • D.G. Luenberger. Introduction to Dynamic Systems, John Wiley & Sons, 1979 • J. Lunze. Regelungstechnik 1, 12. Auflage, Springer, 2020 • J. Lunze. Regelungstechnik 2, 10. Auflage, Springer, 2020 • L. Padulo, M.A. Arbib. System Theory, W.B. Saunders Company, 1974 • W.J. Rugh. Linear System Theory 2, Prentice Hall, 1996

1	**Module name** 97360	**Digitale Regelung** Digital control	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Dr.-Ing. Andreas Michalka
5	**Contents**	Es werden Aufbau u. mathematische Beschreibung digitaler Regelkreise für LZI-Systeme sowie Verfahren zu deren Analyse und Synthese betrachtet: • quasikontinuierliche Beschreibung und Regelung der Strecke unter Berücksichtigung der DA- bzw. AD-Umsetzer • zeitdiskrete Beschreibung der Regelstrecke als Zustandsdifferenzengleichung oder z-Übertragungsfunktion • Analyse von Abtastsystemen, Stabilität, Steuer- und Beobachtbarkeit • Regelungssynthese: Steuerungsentwurf, Zustandsregelung und Beobachterentwurf, Störungen im Regelkreis, Berücksichtigung von Totzeiten, Intersampling-Verhalten".
6	**Learning objectives and skills**	Die Studierenden • erläutern Aufbau und Bedeutung digitaler Regelkreise. • leiten mathematische Beschreibungen des Abtastsystems in Form von Zustandsdifferenzengleichungen oder z-Übertragungsfunktionen her. • analysieren Abtastsysteme und konzipieren digitale Regelungssysteme auf Basis quasikontinuierlicher sowie zeitdiskreter Vorgehensweisen. • entwerfen Steuerungen, Regelungen und Beobachter und bewerten die erzielten Ergebnisse. • diskutieren abtastregelungsspezifische Effekte und bewerten Ergebnisse im Vergleich mit dem kontinuierlichen Systemverhalten.
7	**Prerequisites**	Es wird empfohlen folgende Module zu absolvieren, bevor dieses Modul belegt wird: • Regelungstechnik A (Grundlagen) (RT A) oder Einführung in die Regelungstechnik (ERT) • Regelungstechnik B (Zustandsraummethoden) (RT B)
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Planning & Control - specialization module Master of Science Autonomy Technologies 20232
10	**Method of examination**	Written or oral (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**	german
16	**Bibliography**	

1	**Module name** 95280	**Verteilte Systeme** Distributed systems	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	PD Dr.Ing. Tobias Distler
5	**Contents**	Verteilte Systeme bestehen aus mehreren Rechnern, die über ein Netzwerk miteinander verbunden sind und einen gemeinsamen Dienst erbringen. Obwohl die beteiligten Rechner hierfür in weiten Teilen unabhängig voneinander agieren, erscheinen sie ihren Nutzern gegenüber in der Gesamtheit dabei trotzdem als ein einheitliches System. Die Einsatzmöglichkeiten für verteilte Systeme erstrecken sich über ein weites Spektrum an Szenarien: Von der Zusammenschaltung kleinster Rechenknoten zur Sammlung von Daten im Rahmen von Sensornetzwerken über Steuerungssysteme für Kraftfahrzeuge und Industrieanlagen bis hin zu weltumspannenden, Internet-gestützten Infrastrukturen mit Komponenten in Datenzentren auf verschiedenen Kontinenten. Ziel dieses Moduls ist es, die sich durch die speziellen Eigenschaften verteilter Systeme ergebenden Problemstellungen zu verdeutlichen und Ansätze zu vermitteln, mit deren Hilfe sie gelöst werden können; Beispiele hierfür sind etwa die Interaktion zwischen heterogenen Systemkomponenten, der Umgang mit erhöhten Netzwerklatenzen sowie die Wahrung konsistenter Zustände über 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**	Written examination
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** 92430	**Ereignisdiskrete Systeme**	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Thomas Moor
5	**Contents**	Formale Sprachen als Modelle ereignisdiskreter Dynamik • reguläre Ausdrücke, endliche Automaten, Nerode-Äquivalenz • natürliche Projektion, synchrone Komposition, Konfliktfreiheit. Entwurf ereignisdiskreter Regler: • Sicherheitsspezifikation, Konfliktfreiheit • supremale steuerbare Teilsprache, Fixpunktiterationen • Normalität, Regelung unter eingeschränkter Beobachtbarkeit. Anwendungsstudie: • Modellbildung eines einfachen technischen Prozesses • Spezifikation/Entwurf/Simulation am Anwendungsbeispiel
6	**Learning objectives and skills**	Teilnehmer dieser Veranstaltung • erklären, illustrieren und validieren die vorgestellten Grundlagen formaler Sprachen, • entwickeln einfache Ergänzungen zu den vorgestellten Grundlagen formaler Sprachen, • erklären und illustrieren die vorgestellten Entwurfsverfahren, • überprüfen die vorgestellten Entwurfsverfahren hinsichtlich einzelner Lösungseigenschaften, • entwickeln ereignisdiskrete Modelle einfacher technischer Prozesse, einschließlich formaler Spezifikationen, • wählen im Kontext einfacher technischer Prozesse geeignete Entwurfsverfahren aus und wenden diese kritisch an, • bewerten ihre Regelkreise im Simulationsexperiment.
7	**Prerequisites**	Es wird empfohlen, eines der folgenden Module zu absolvieren, bevor dieses Modul belegt wird: • Regelungstechnik A (Grundlagen) (RT A) • Einführung in die Regelungstechnik (ERT)
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Planning & Control - specialization module Master of Science Autonomy Technologies 20232
10	**Method of examination**	Written or oral
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german

16	**Bibliography**	Cassandras, C.G., Lafortune, S.: Introduction to Discrete Event Systems, Kluwer, 1999

1	**Module name** 94951	**Grundlagen der Robotik** Fundamentals of robotics	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Jörg Franke
5	**Contents**	Die Veranstaltung Grundlagen der Robotik richtet sich insbesondere an die Studierenden der Informatik, des Maschinenbaus, der Mechatronik, der Medizintechnik sowie des Wirtschaftsingenieurwesens. Im Rahmen der Veranstaltung 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. Im Rahmen der letzten Vorlesungseinheiten sowie der Übungseinheiten werden dem Hörer weiterhin die Grundlagen des Robot Operating System (ROS) vermittelt und es wird durch praktische Übungen die Arbeit und Roboterprogrammierung mit ROS erlernt. Die Veranstaltung 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 der Vorlesung 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. Nach dem Besuch der Veranstaltung sind die Studierenden 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** 48440	**Machine Learning in Signal Processing** Machine learning in signal processing	**5 ECTS**
2	Courses / lectures	Übung: Supplements for Machine Learning in Signal Processing (2 SWS) Vorlesung: Machine Learning in Signal Processing (3 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr. Vasileios Belagiannis	

4	**Module coordinator**	PD Dr.Ing. Jürgen Seiler
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)
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	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	PD Dr.Ing. Christian Riess
5	**Contents**	This module introduces the design of pattern analysis systems as well as the corresponding fundamental mathematical methods. The topics comprise: • clustering methods: soft and hard clustering • classification and regression trees and forests • parametric and non-parametric density estimation: maximum-likelihood (ML) estimation, maximum-a-posteriori (MAP) estimation, histograms, Parzen estimation, relationship between folded histograms and Parzen estimation, adaptive binning with regression trees • mean shift algorithm: local maximization using gradient ascent for non-parametric probability density functions, application of the mean shift algorithm for clustering, color quantization, object tracking • linear and non-linear manifold learning: curse of dimensionality, various dimensionality reduction methods: principal component analysis (PCA), multidimensional scaling (MDS), isomaps, Laplacian eigenmaps • Gaussian mixture models (GMM) and hidden Markov models (HMM): expectation maximization algorithm, parameter estimation, computation of the optimal sequence of states/ Viterbi algorithm, forward-backward algorithm, scaling • Markov random fields (MRF): definition, probabilities on undirected graphs, clique potentials, Hammersley-Clifford theorem, inference via Gibbs sampling and graph cuts Das Modul führt in das Design von Musteranalysesystemen sowie die zugrundeliegenden mathematischen Methoden ein. Die Vorlesung umfasst im Einzelnen: • Clustering-Methoden: Soft- und Hard-Clustering • Klassifikations- und Regressionsbäume/-wälder • parametrische und nicht-parametrische Dichteschätzung: Verfahren sind ML- und MAP-Schätzung, Histogramme, Parzenschätzung, Zusammenhang gefaltete Histogramme und Parzenschätzung, adaptives Binning mit Regressionsbäumen. • 'Mean Shift'-Algorithmus: lokale Maximierung durch Gradientenaufstieg bei nicht-parametrischen Dichtefunktionen, Anwendungen des 'Mean Shift'-Algorithmus zum Clustering, Farbquantisierung und Objektverfolgung • Linear and Non-Linear Manifold Learning: Curse of Dimensionality, Verschiedene Methode zur Dimensionsreduktion: Principal Component Analysis (PCA),

		Multidimensionsional Scaling (MDS), Isomap, Laplacian Eigenmaps • Gaußsche Mischverteilungsmodelle (GMM) und Hidden-Markov-Modelle (HMM): 'Expectation Maximization'-Algorithmus, Parameterschätzung, Bestimmung der optimalen Zustandsfolge/Viterbi-Algorithmus, Vorwärts-Rückwärts-Algorithmus, Skalierung • Markov-Zufallsfelder: Definition, Wahrscheinlichkeiten auf ungerichteten Graphen, Cliquen-Potenziale, Hammersley-Clifford-Theorem, Inferenz mit Gibbs-Sampling und Graph Cuts
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, • implement presented methods in Python, • supplement autonomously the mathematical foundations of the presented methods by self-guided study of the literature, • discuss the social impact of applications of pattern analysis solutions. Die Studierenden • erläutern die behandelten Methoden zur Klassifikation, Vorhersage und Analyse von Mustern, • vergleichen und analysieren Methoden des Manifold Learning und wählen für eine vorgegebene Fragestellung eine geeignete Methode aus, • vergleichen und analysieren Methoden zur Dichteschätzung und wählen für eine vorgegebene Fragestellung eine geeignete Methode aus, • wenden nicht-parametrische Dichteschätzung auf Probleme der Musteranalyse an, • wenden Dimensionsreduktion bei hochdimensionalen Merkmalsräumen an, • erläutern statistische Modellierung von Merkmalsmengen und Merkmalsfolgen, • erklären statistische Modellierung abhängiger Größen, • implementieren vorgestellte Verfahren in Python.

		• ergänzen eigenständig mathematische Grundlagen der präsentierten Methoden durch selbstbestimmtes Studium der Literatur • diskutieren die gesellschaftlichen Auswirkungen von Anwendungen der Musteranalyse
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)
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	Paul Stöwer Siming Bayer Prof. Dr.-Ing. Andreas Maier	

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

		• beurteilen unterschiedliche Klassifikatoren in Bezug auf ihre Eignung • verstehen in der Programmiersprache Python geschriebene Lösungen von Klassifikationsproblemen und Implementierungen von Klassifikatoren Students • understand the structure of machine learning systems for simple patterns • explain the mathematical foundations of selected machine learning techniques • apply classification techniques in order to solve given classification tasks • evaluate various classifiers with respect to their suitability to solve the given problem • understand solutions of classification problems and implementations of classifiers written in the programming language Python
7	**Prerequisites**	• Well grounded in probability calculus, linear algebra/matrix calculus • The attendance of our bachelor course 'Introduction to Pattern Recognition' is not required but certainly helpful. • Gute Kenntnisse in Wahrscheinlichkeitsrechnung und Linearer Algebra/Matrizenrechnung • Der Besuch der Bachelor-Vorlesung 'Introduction to Pattern Recognition' ist zwar keine Voraussetzung, aber sicherlich von Vorteil.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Planning & Control - specialization module 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** 93185	**Reinforcement Learning**	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Dr.-Ing. Christopher Mutschler
5	**Contents**	The lecture aims at teachin Reinforcement Learning (RL) and will cover the following topics: • Introduction to Reinforcement Learning (Agent-Environment-Interface, Markov Decision Processes) • Dynamic Programming (Bellman Equations, Value Iteration, Policy Iteration) • Model-Free Prediction • Model-Free Control • Value Function Approximation (Linear VFA and DQNs) • Policy-based Reinforcement Learning (Monte-Carlo Policy Gradient, Advantage Estimators, TRPO, PPO) • Model-based RL • Offline RL • Explainable RL • Exploration-Exploitation • Simulation to Reality Transfer • Research frontiers & hot topics, Sim2Real & Real-World Applications
6	**Learning objectives and skills**	The students will learn to • understand the basic principle behind sequestration decision making problems and how to translate them into a formal model • compare and analyze methods different agents to search for policies • implement the presented methods in PyTorch, • discuss the social impact of applications that automate decision making
7	**Prerequisites**	Es handelt sich hier um eine Spezialisierungsvorlesung, eine erfolgreiche Absolvierung der Vorlesungen IntroPR" und/oder Pattern Recognition"/"Pattern Analysis" wird empfohlen. Konzepte, die in IntroPR" vermittelt werden, werden hier als Grundwissen vorausgesetzt.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Planning & Control - specialization module Master of Science Autonomy Technologies 20232
10	**Method of examination**	Variable
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 S. Sutton and Andrew G. Barto. 2018. Reinforcement Learning: An Introduction. A Bradford Book, Cambridge, MA, USA. • Bellman, R.E. 1957. Dynamic Programming. Princeton University Press, Princeton, NJ. Republished 2003: Dover, ISBN 0-486-42809-5. • Csaba Szepesvari and Ronald Brachman and Thomas Dietterich. 2010. Algorithms for Reinforcement Learning. Morgan and Claypool Publishers. • Warren B. Powell. 2011. Approximate Dynamic Programming. Wiley. • Maxim Lapan. 2020. Deep Reinforcement Learning Hands-On: Apply modern RL methods to practical problems of chatbots, robotics, discrete optimization, web automation, and more, 2nd Edition. Packt Publishing. • Dimitri P. Bertsekas. 2017. Dynamic Programming and Optimal Control. Athena Scientific. • Miguel Morales. 2020. grokking Deep Reinforcement Learning. Manning. • Laura Graesser and Keng Wah Loon. 2019. Foundations of Deep Reinforcement Learning: Theory and Practice in Python. Addison-Wesley Data & Analytics.

1	**Module name** 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**	Prof. Dr.-Ing. Knut Graichen Dr.-Ing. Andreas Völz
5	**Contents**	This lecture introduces advanced methods of robotics with a focus on manipulator control. The course covers the following topics: • Dynamics: Euler-Lagrange formulation, recursive Newton-Euler algorithm, extensions of the dynamical model • Nonlinear control: Lyapunov stability, gravity compensation, inverse dynamics, adaptive control, task space control • Motion planning: Time-optimal trajectory generation, collision checking, configuration space, local path planning, global path planning • Mobile robots: Basics of control and planning
6	**Learning objectives and skills**	The students are able to • derive the dynamical model of a robotic manipulator • design and implement nonlinear methods for robot motion and force control • plan collision-free motions for robots in known environments
7	**Prerequisites**	• Basics of advanced mathematics • Basics of control theory • Basics of 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
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** 92880	**Robotics Frameworks**	**5 ECTS**
2	Courses / lectures	Vorlesung: Robotics Frameworks (4 SWS) Übung: Exercise Robotics Frameworks (0 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Dr.-Ing. Sebastian Reitelshöfer	

4	**Module coordinator**	Prof. Dr.-Ing. Jörg Franke
5	**Contents**	• Basic concepts of robotics • Basic concepts of the Robot Operating System • Simulation of robots in virtual environments • Computer vision and machine learning in the context of robotics • Path and gripping grasp planning • Localization, mapping and navigation of mobile robots • Flow control with state machines for complex robot tasks • Introduction to relevant software frameworks for specific tasks (Robot Operating System, Gazebo, OpenCV, Tensorflow) • Solving a complex practical task as a team
6	**Learning objectives and skills**	In this module, students independently implement advanced tasks in robotics and related topics such as simulation, computer vision and machine learning using concrete examples. In doing so, the students deal with various established software frameworks and learn how to use them. Students are taught the following technical and methodological competences: After completing the module, students will be able to • Classify important terms of robotics • Understand the challenges of modern robotics in relation to complex tasks and develop approaches to solve them. • Analyse and practically apply complex issues in robotics (robotics frameworks, simulation tools and frameworks for image processing and artificial intelligence) • Explain and apply methods of robot motion control and planning • Explain the self-localisation of mobile robots and examine it using examples The students additionally acquire and train the following personal and social competences within the framework of the team task: After completing the module, the students can • Independently solve preparatory tasks • Organize their working time • Work together with other students in a group in a goal-oriented manner • Assess their own strengths and use them in a targeted way in the team performance
7	**Prerequisites**	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** 94961	**Schätzverfahren in der Regelungstechnik**	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Thomas Moor
5	**Contents**	• Überbestimmte lineare Gleichungssysteme zur Parameter- und Zustandsschätzung • Least Squares Schätzer via quadratischer Ergänzung • Least Squares Schätzer via Projektionssatz • Linear Least Mean Squares Schätzer stochastischer Größen • Kalman-Filter • Extended Kalman-Filter
6	**Learning objectives and skills**	Die Studierenden • erkennen, ob und wie eine regelungstechnische Problemstellung in dem vorgestellten Rahmen der Schätzverfahren formuliert und gelöst werden kann • erläutern die herangezogenen mathematischen Grundlagen, insbesondere aus der linearen Algebra • können die vermittelten Ansätze im Kontext von einfachen Beispielen anwenden und die jeweils erzielten Ergebnisse kritisch bewerten.
7	**Prerequisites**	Grundlagen der Analysis und Algebra, wie sie z.B. in den Veranstaltungen "Mathematik für Ingenieure" angeboten werden; Grundlagen der Regelungstechnik, z.B. durch Belegung der Module: • Regelungstechnik A (Grundlagen) • Regelungstechnik B (Zustandsraummethoden)
8	**Integration in curriculum**	semester: 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 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** 96430	**Statistical Signal Processing** Statistical signal processing	**5 ECTS**
2	Courses / lectures	Übung: Ergänzungen und Übungen zur statistischen Signalverarbeitung (1 SWS) Vorlesung: Statistische Signalverarbeitung (3 SWS)	- 5 ECTS
3	Lecturers	Annika Briegleb Prof. Dr.-Ing. Walter Kellermann	

4	**Module coordinator**	Prof. Dr.-Ing. Walter Kellermann
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 *Zeitdiskrete Zufallsprozesse im Zeit- und Frequenzbereich* Zufallsvariablen (ZVn), Wahrscheinlichkeitsverteilungen und dichten, Erwartungswerte; Transformation von ZVn; Vektoren normalverteilter ZVn; zeitdiskrete Zufallsprozesse (ZPe): Wahrscheinlichkeitsverteilungen und dichten, Erwartungswerte, Stationarität, Zyklostationarität, Ergodizität, Korrelationsfunktionen und -matrizen, Spektraldarstellungen; Principal Component Analysis, Karhunen-Loeve Transformation; *Schätztheorie*

		Schätzkriterien; Prädiktion; klassische und Bayessche Parameterschätzung (inkl. MMSE, Maximum Likelihood, Maximum A Posteriori); Cramer-Rao-Schranke *Lineare Signalmodelle* Parametrische Modelle (Cepstrale Zerlegung, Paley-Wiener Theorem, Spektrale Glattheit); Nichtparametrische Modelle: Allpole-/Allzero-/ Pole-zero-(AR/MA/ARMA) Modelle; Lattice-Strukturen, Yule-Walker Gleichungen, PARCOR-Koeffizienten, Cepstraldarstellungen; *Signalschätzung* Überwachte Signalschätzung, Problemklassen; Orthogonalitätsprinzip, MMSE-Schätzung, lineare MMSE-Schätzung für Gaußprozesse; Optimale FIR-Filter; Lineare Optimalfilter für stationäre Prozesse; Prädiktion und Glättung; Kalman-Filter; optimale Multikanalfilterung (Wiener-Filter, LCMV, MVDR, GSC); *Adaptive Filterung* Gradientenverfahren; LMS-, NLMS-, APA- und RLS-Algorithmus und Ihr Konvergenzverhalten.
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. Die Studierenden • analysieren die statistischen Eigenschaften von Zufallsvariablen, -vektoren und stochastischen Prozessen mittels Wahrscheinlichkeitsdichten und Erwartungswerten, bzw. Korrelationsfunktionen, Korrelationsmatrizen und deren Frequenzbereichsdarstellungen • kennen die spezielle Rolle der Gaußverteilung und ihre Auswirkungen auf die Eigenschaften von Zufallsvariablen, -vektoren und Prozessen • verstehen die Unterschiede klassischer und Bayesscher Schätzung, entwerfen und analysieren MMSE- und ML-Schätzer für spezielle Schätzprobleme, insbesondere zur Signalschätzung • analysieren und evaluieren lineare MMSE-optimale Schätzer (ein- und vielkanalige Wiener-Filter und Kalman-Filter) für direkte und inverse überwachte Schätzprobleme;

		• evaluieren adaptive Filter zur Identifikation optimaler linearer Signalschätzer
7	**Prerequisites**	Module Signale und Systeme I und Signale und Systeme II, Digitale Signalverarbeitung oder gleichwertige
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)
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 (englisch) D. Manolakis, V. Ingle, S. Kogon: Statistical and Adaptive Signal Processing; Artech House, 2005 (englisch)

1	**Module name** 44500	**Swarm Intelligence**	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Rolf Wanka
5	**Contents**	Swarm Intelligence (SI) is the design and deployment of self-organizing systems that dynamically adapt to their respective environmental needs. These systems are characterized by the fact that they feature the so-called self-*-properties, i.e., they are self-configuring, self-optimizing, self-healing, self-protecting, self-explanatory, ... Structures and methods of biological and other natural systems are chosen as models for such technical systems. In this module, Particle Swarm Optimization, Ant Algorithms, Web Search, and Evolutionary Algorithms are introduced and, as far as possible, mathematically analyzed.
6	**Learning objectives and skills**	Students learn advanced concepts of the current topic of swarm intelligence and how they can be successfully applied to solve continuous and discrete optimization problems and to data analysis. For this purpose, they know concrete details such as terms, definitions, facts, regularities and theories and learn how to apply the concepts to concrete problems, how to adjust the methods to the use case and how to analyze the computed solutions.
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 (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**	• Ch. Müller-Schloer, Ch. von der Malsburg, R. P. Würt. Organic Computing. Informatik-Spektrum, Band 27, Nummer 4, S. 332-336. • I. C. Trelea. The particle swarm optimization algorithm: convergence analysis and parameter selection. Information Processing Letters 85 (2003) 317-325. • J. M. Kleinberg. Authoritative sources in a hyperlinked environment. Journal of the ACM 46 (1999) 604-632.

		• M. Dorigo. V. Maniezzo. A Colorni. Ant system: an autocatalytic optimizing process. Technical Report 91-016, Politecnico di Milano, 1991. • A. Badr. A. Fahmy. A proof of convergence for Ant algorithms. Information Sciences 160 (2004) 267-279. • M. Clerc. J. Kennedy. The particle swarm - Explosion, stability, and convergence in a multidimensional complex space. IEEE Transactions on Evolutionary Computation 8 (2002) 58-73

Planning & Control - Seminar & Laboratory

1	**Module name** 92338	**Lab Course Automatic Control I**	**2,5 ECTS**
2	Courses / lectures	Praktikum: Praktikum Regelungstechnik I (3 SWS)	-
3	Lecturers	Dr.-Ing. Andreas Michalka Prof. Dr.-Ing. Knut Graichen Prof. Dr. Thomas Moor Dr.-Ing. Andreas Völz	

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**	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
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**	**2,5 ECTS**
2	Courses / lectures	Praktikum: Praktikum Regelungstechnik II (3 SWS)	-
3	Lecturers	Dr.-Ing. Andreas Völz Prof. Dr.-Ing. Knut Graichen Prof. Dr. Thomas Moor Dr.-Ing. Andreas Michalka	

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
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 or 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)	2,5 ECTS
3	Lecturers	Prof. Dr. Vasileios Belagiannis Youssef Dawoud	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup
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**	Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	
11	**Grading procedure**	
12	**Module frequency**	every semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 15 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 97535	**Laborpraktikum Statistische Signalverarbeitung**	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Walter Kellermann
5	**Contents**	After an introduction to scientific programming with Python, experiments and exercises related to the following topics are carried out during the laboratory course: Fundamental properties of random variables and stochastic processes Properties of correlations matrices, Principal Component Analysis (PCA), KLT Parametric and non-parametric linear signal models MMSE signal estimation Kalman filtering with applications to source tracking Optimum multichannel filtering Introduction to adaptive filtering. In the second phase of the lab course, the students will work in small project teams on relevant research problems. Nach einer Einführung in den Gebrauch der Programmiersprache Python werden Experimente und Übungen zu folgenden Themen der Statistischen Signalverarbeitung durchgeführt: • Grundlegende Eigenschaften von Zufallsvariablen und stochastischer Prozesse • Eigenschaften von Korrelationsmatrizen, Hauptachsentransformation, KLT • Parametrische und nicht-parametrische lineare Signalmodelle • MMSE-Signalschätzung • Kalman-Filterung mit Anwendungen zur Signalquellenverfolgung • Optimale Mehrkanalfilterung, • Einführung in die adaptive Filterung. In der zweiten Phase des Praktikums werden die Studenten in kleinen Projektgruppen (max. 3 Studenten) selbstständig eine forschungsrelevante Problemstellung analysieren und mögliche Lösungssansätze erarbeiten, implementieren und evaluieren.
6	**Learning objectives and skills**	The students implement Python codes to solve described problems and apply their collected knowledge, analyze, evaluate and discuss the implemented algorithms, familiarize themselves with the necessary steps to implement theoretical models, reflect their learning progress during the laboratory. Die Studenten

		• verfassen Python-Programme zu den einzelnen vorgezeichneten Experimenten und wenden damit das in Vorlesung und Übung erworbene Wissen an, • analysieren und evaluieren implementierte Algorithmen, • erlernen die notwendigen Schritte zur praktischen Umsetzung von theoretischen Modellen, • reflektieren ihren eigenen Lernprozess während des Praktikums.
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 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	
11	**Grading procedure**	
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** 92342	**Seminar Mobile Robotics**	**2,5 ECTS**
2	Courses / lectures	Seminar: Seminar Mobile Robotics (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Knut Graichen	

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**	Registration via StudOn is required for this 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**	Seminar achievement
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german or english
16	**Bibliography**	

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

4	**Module coordinator**	Prof. Dr.-Ing. Knut Graichen Prof. Dr. 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
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**	german or english
16	**Bibliography**	

Sensing & Perception - core modules

1	**Module name** 92343	**Image, Video, and Multidimensional Signal Processing**	**5 ECTS**
2	Courses / lectures	Vorlesung: Bild-, Video- und mehrdimensionale Signalverarbeitung (2 SWS) Übung: Übung zu Bild-, Video- und mehrdimensionale Signalverarbeitung (SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Andre Kaup Andy Regensky	

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**	
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: Supplements for Machine Learning in Signal Processing (2 SWS) Vorlesung: Machine Learning in Signal Processing (3 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr. Vasileios Belagiannis	

4	**Module coordinator**	PD Dr.Ing. Jürgen Seiler
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)
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** 96316	**Radar, RFID and Wireless Sensor Systems (RWS)**	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Martin Vossiek
5	**Contents**	Radar, RFID and wireless sensor and wireless locating systems are essential for automotive advanced driver-assistance systems (ADAS), 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 (90 minutes)
11	**Grading procedure**	Written (100%)
12	**Module frequency**	only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english

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

1	**Module name** 96430	**Statistical Signal Processing** Statistical signal processing	**5 ECTS**
2	Courses / lectures	Übung: Ergänzungen und Übungen zur statistischen Signalverarbeitung (1 SWS) Vorlesung: Statistische Signalverarbeitung (3 SWS)	- 5 ECTS
3	Lecturers	Annika Briegleb Prof. Dr.-Ing. Walter Kellermann	

4	**Module coordinator**	Prof. Dr.-Ing. Walter Kellermann
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 *Zeitdiskrete Zufallsprozesse im Zeit- und Frequenzbereich* Zufallsvariablen (ZVn), Wahrscheinlichkeitsverteilungen und dichten, Erwartungswerte; Transformation von ZVn; Vektoren normalverteilter ZVn; zeitdiskrete Zufallsprozesse (ZPe): Wahrscheinlichkeitsverteilungen und dichten, Erwartungswerte, Stationarität, Zyklostationarität, Ergodizität, Korrelationsfunktionen und -matrizen, Spektraldarstellungen; Principal Component Analysis, Karhunen-Loeve Transformation; *Schätztheorie*

		Schätzkriterien; Prädiktion; klassische und Bayessche Parameterschätzung (inkl. MMSE, Maximum Likelihood, Maximum A Posteriori); Cramer-Rao-Schranke *Lineare Signalmodelle* Parametrische Modelle (Cepstrale Zerlegung, Paley-Wiener Theorem, Spektrale Glattheit); Nichtparametrische Modelle: Allpole-/Allzero-/ Pole-zero-(AR/MA/ARMA) Modelle; Lattice-Strukturen, Yule-Walker Gleichungen, PARCOR-Koeffizienten, Cepstraldarstellungen; *Signalschätzung* Überwachte Signalschätzung, Problemklassen; Orthogonalitätsprinzip, MMSE-Schätzung, lineare MMSE-Schätzung für Gaußprozesse; Optimale FIR-Filter; Lineare Optimalfilter für stationäre Prozesse; Prädiktion und Glättung; Kalman-Filter; optimale Multikanalfilterung (Wiener-Filter, LCMV, MVDR, GSC); *Adaptive Filterung* Gradientenverfahren; LMS-, NLMS-, APA- und RLS-Algorithmus und Ihr Konvergenzverhalten.
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. Die Studierenden • analysieren die statistischen Eigenschaften von Zufallsvariablen, -vektoren und stochastischen Prozessen mittels Wahrscheinlichkeitsdichten und Erwartungswerten, bzw. Korrelationsfunktionen, Korrelationsmatrizen und deren Frequenzbereichsdarstellungen • kennen die spezielle Rolle der Gaußverteilung und ihre Auswirkungen auf die Eigenschaften von Zufallsvariablen, -vektoren und Prozessen • verstehen die Unterschiede klassischer und Bayesscher Schätzung, entwerfen und analysieren MMSE- und ML-Schätzer für spezielle Schätzprobleme, insbesondere zur Signalschätzung • analysieren und evaluieren lineare MMSE-optimale Schätzer (ein- und vielkanalige Wiener-Filter und Kalman-Filter) für direkte und inverse überwachte Schätzprobleme;

		• evaluieren adaptive Filter zur Identifikation optimaler linearer Signalschätzer
7	**Prerequisites**	Module Signale und Systeme I und Signale und Systeme II, Digitale Signalverarbeitung oder gleichwertige
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)
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 (englisch) D. Manolakis, V. Ingle, S. Kogon: Statistical and Adaptive Signal Processing; Artech House, 2005 (englisch)

Sensing & Perception - specialization module

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 Benedikt Beck	

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**	**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)
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** 93173	**Computational Visual Perception**	**7,5 ECTS**
2	Courses / lectures	Vorlesung: Computational Visual Perception (4 SWS) Projektseminar: Tutorials to Computational Visual Perception (2 SWS)	2,5 ECTS 5 ECTS
3	Lecturers	Prof. Dr. Andreas Kist Dr. rer. nat. Patrick Krauß 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**	Tutorial achievement

		Written (60 minutes)
11	**Grading procedure**	Tutorial achievement (0%) Written (100%)
12	**Module frequency**	only in winter semester
13	**Workload in clock hours**	Contact hours: 90 h Independent study: 135 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 96401	**Globale Navigationssatellitensysteme** Global navigation satellite systems	**5 ECTS**
2	Courses / lectures	Übung: Übung zu Globale Navigationssatellitensysteme (1 SWS) Vorlesung: Globale Navigationssatellitensysteme (3 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr. Jörn Thielecke	

4	**Module coordinator**	Prof. Dr. Jörn Thielecke
5	**Contents**	*Hinweis:* 1. Mehrere Übungsstunden werden rechnergestützt (Python) sein, um den Vorlesungsstoff durch eigene praktische Erfahrung zu vertiefen. 2. Eine Laborbesichtigung beim Fraunhofer Institut für Integrierte Schaltungen soll den Studierenden Einblick in die einschlägigen Arbeiten zu GPS und Galileo geben. *Inhalte:* *|1. Überblick: Signale und Systeme|* • Einführung • GPS Global Positioning System • Galileo • Satellitenergänzungssysteme: EGNOS, WAAS, LAAS • Mathematische Grundlagen: Navigationssignale, Gold Codes, Cramer-Rao-Schranke für Laufzeitmessungen *|2. Grundlagen und Funktiosweise der Satellitenortung|* • Koordinatensysteme, Zeitsysteme und Orbits • Ausbreitungsbedingungen und Fehlerquellen • Positions-, Geschwindigkeits- und Zeitschätzung • Hochgenaue Positionsschätzung mittels Trägerphase *|3. GNSS Empfänger|* • Signalkonditionierung • Leistungsfähigkeit der GPS- und Galileo-Signale • Releschleifen zur Signalverfolgung
6	**Learning objectives and skills**	1. Eine Übersicht über die Möglichkeiten von GPS und Galileo soll die Beurteilungsfähigkeit der Studierenden für neue Anwendungen schärfen. 2. Durch vertiefte Kenntnisse der Grundlagen, Funktionsweise und Fehlerquellen sollen die Studierenden die gelösten Herausforderungen und die Grenzen von GPS und Galileo einschätzen lernen. 3. Die Studierenden sollen ein nachrichtentechnisches Verständnis für die Funktionsweise eines GPS-Empfängers erlangen.
7	**Prerequisites**	Keine formalen Voraussetzungen, grundlegende Kenntnisse erforderlich in: linearer Algebra, Signal- & Systemtheorie, Wahrscheinlichkeitstheorie
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Sensing & Perception - specialization module Master of Science Autonomy Technologies 20232

10	**Method of examination**	Written or oral
11	**Grading procedure**	Written or oral (100%) Bei bestandener Prüfung wird die Note um eine Teilnotenstufe (z.B. von 2,0 auf 1,7) verbessert, wenn Sie: 1. Mindestens 75% der Hausaufgaben bestanden haben UND 2. Mindestens 75% der Rechnerübungen erfolgreich absolviert haben. Eine Note besser als 1,0 wird nicht vergeben.
12	**Module frequency**	only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german
16	**Bibliography**	1. Pratap Misra, Per Enge, Global Positioning System", Ganga-Jamuna Press, 2001 2. E.D. Kaplan, C.J. Hegarty, Understanding GPS Principles and Applications"Artech House, 2. Auflage, 2006 3. Werner Mansfeld, "Satellitenortung und Navigation, Vieweg, 2004

1	**Module name** 96310	**Image and Video Compression** Image and video compression	**5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup
5	**Contents**	*Multi-Dimensional Sampling* Sampling theorem revisited, 2D sampling, spatiotemporal sampling, motion in 3D sampling *Entropy and Lossless Coding* Entropy and information, variable length codes, Huffman coding, unary coding, Golomb coding, arithmetic coding *Statistical Dependency* Joint entropy and statistical dependency, run-length coding, fax compression standards *Quantization* Rate distortion theory, scalar quantization, Lloyd-Max quantization, entropy coded scalar quantization, embedded quantization, adaptive quantization, vector quantization *Predictive Coding* Lossless predictive coding, optimum 2D linear prediction, JPEG-LS lossless compression standard, differential pulse code modulation (DPCM) *Transform Coding* Principle of transform coding, orthonormal transforms, Karhunen-Loève transform, discrete cosine transform, bit allocation, compression artifacts *Subband Coding* Principle of subband coding, perfect reconstruction property, discrete wavelet transform, bit allocation for subband coding *Visual Perception and Color* Anatomy of the human eye, sensitivity of the human eye, color spaces, color sampling formats *Image Coding Standards* JPEG and JPEG2000 *Interframe Coding* Interframe prediction, motion compensated prediction, motion estimation, motion compensated hybrid coding *Video Coding Standards* H.261, H.263, MPEG-1, MPEG-2 / H.262, H.264 / MPEG-4 AVC, H.265 / MPEG-H HEVC
6	**Learning objectives and skills**	Die Studierenden • veranschaulichen die mehrdimensionale Abtastung und den Einfluss darauf durch Bewegung im Videosignal • unterscheiden und bewerten verschiedene Verfahren zur verlustfreien Codierung von Bild- und Videodaten • verstehen und analysieren Verbundentropie und statistische Abhängigkeiten in Bild- und Videodaten

		• berechnen skalare und vektorielle Quantisierer nach unterschiedlichen Optimierungsvorgaben (minimaler mittlerer quadratischer Fehler, entropiecodiert, eingebetteter Quantisierer) • bestimmen und evaluieren optimale ein- und zwei-dimensionale lineare Prädiktoren • wenden Prädiktion und Quantisierung sinnvoll in einem gemeinsamen DPCM-System an • verstehen das Prinzip und die Effekte von Transformations- und Teilbandcodierung für Bilddaten einschließlich optimaler Bitzuteilungen • beschreiben die Grundzüge der menschlichen visuellen Wahrnehmung für Helligkeit und Farbe • analysieren Blockschaltbilder und Wirkungsweisen hybrider Coder und Decoder für Videosignale • kennen die maßgeblichen internationalen Standards aus ITU und MPEG zur Bild- und Videokompression. 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**	Modul Signale und Systeme II" und das Modul Nachrichtentechnische Systeme"
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)

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", Berlin: Springer-Verlag, 2004

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 und linearer Algebra. Von Vorteil wären zudem Vorkenntnisse auf einem Teil der folgenden Gebiete: statistische Signalverarbeitung, Hochfrequenztechnik, Radar und/oder 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
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. • The following literature can be consulted if detailed information is needed on individual aspects: - M. Richards, Fundamentals of Radar Signal Processing, McGraw-Hill, 2nd ed., 2014 - I. Cumming, F. Wong, Digital Processing of Synthetic Aperture Radar Data, Artech House, 2004 - J. Curlander, R. Donough, Synthetic Aperture Radar Systems & Signal Processing, Wiley, 1991 - F. Ulaby, D. Long, Microwave Radar and Radiometric Remote Sensing, Michigan Press, 2014 - C. Oliver, S. Quegan, Understanding Synthetic Aperture Images, Scitech, 2004 - H. Van Trees, Optimum Array Processing, Wiley Interscience, 2002 - J. Guerci, Space-Time Adaptive Processing for Radar, Artech House, 2nd ed., 2015 - R. Hanssen, Radar Interferometry, Kluwer Academic Publishers, 2001 - J. Li, P. Stoica, MIMO Radar Signal Processing, Wiley, 2008

1	**Module name** 96314	**Virtual Vision** Virtual vision	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Virtual Vision (2 SWS)	2,5 ECTS
3	Lecturers	Dr.-Ing. Christian Herglotz	

4	**Module coordinator**	Dr.-Ing. Christian Herglotz
5	**Contents**	Menschliches Sehen Sichtfeld und Fovea Dynamic Range Stereoskopie Eigenschaften der Lichtfeldunktion • Helligkeit • 3D und Tiefe • Farben • Räumliche und zeitliche Auflösung Energieeffizienz in der Videokommunikation. Content: Human Vision Field of view and fovea Dynamic Range Stereoscopy Properties of the light field funtion • Brightness • 3D and depth • Colors • Spatial and temporal resolution Energy efficiency in video communications
6	**Learning objectives and skills**	The students • give an overview on basic properties of the human visual system • know and explain all hardware and software components necessary to perform video capturing, processing, and display. • describe differences and properties of video formats such as fisheye, 360°, or high dynamic range • distinguish video formats and discuss advantages and disadvantages • show real-time demonstrations of these video formats with common portable devices • assess the quality and the compression performance of video formats • come up with new strategies to improve processing algorithms like stitching or compression.
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 or oral

11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	only in winter semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	
16	**Bibliography**	Literaturhinweise werden in der Vorlesung gegeben. References for further reading will be given in the lecture.

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.-Ing. Bernhard Schmauß Prof. Dr. Nicolas Joly	

4	**Module coordinator**	Prof. Dr. Nicolas Joly Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	1) Fundamental of waveguides (Guidance mechanism, modes and dispersion, geometrical and electromagnetic approach) 2) Photonic crystal fibres (PCF) 3) Nonlinear optics in PCF (soliton, supercontinuum generation, nonlinear optics in gases in hollow-core PCF) 4) Optical communication systems (system outline, waveguide components, transmission effects, performance limitations) 5) Optical fibre sensors: fibre sensing principles, waveguide-based sensing component, distributed sensing, sensor, network, sensor signal processing)
6	**Learning objectives and skills**	The students will be able • to identify a particular type of microstructure fibre for a dedicated experiment • to calculate the mode content supported by a specific fibre and model the modal properties • to evaluate the potential limitations of an optical fibre due to nonlinear effects • to choose the appropriate fibre (dispersion and nonlinearity) to generate quiet or very broad supercontinuum spectral using a photonic crystal fibre • to choose the appropriate type of fibre-based sensor according to the signal to probe • \to understand the performance limitation of the telecommunications systems
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Sensing & Perception - specialization module 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**	

Sensing & Perception - Seminar & Laboratory

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)	2,5 ECTS
3	Lecturers	Prof. Dr. Vasileios Belagiannis Youssef Dawoud	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup
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**	Planning & Control - Seminar & Laboratory Master of Science Autonomy Technologies 20232 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	
11	**Grading procedure**	
12	**Module frequency**	every semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 15 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 97651	**Laborpraktikum Image and Video Compression** Laborpraktikum Multimediakommunikation	**2,5 ECTS**
2	Courses / lectures	The teaching units in the module are only offered in the summer semester.	
3	Lecturers	-	

4	**Module coordinator**	Dr.-Ing. Christian Herglotz
5	**Contents**	• Einführung in die Programmierumgebung MATLAB • Realisierung der Verarbeitungsblöcke von Videocodern • Aufbau eines Videocodecs und optionale Erweiterungen • Durchführung eines subjektiven Vergleichs verschiedener Videocodecs • Präsentation und kritische Beurteilung der Ergebnisse *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**	Die Studierenden • erzeugen ein funktionsfähiges Programmsystem mit der Programmierumgebung MATLAB, • beurteilen die Funktionsblöcke von Video-Codern, • gestalten ihren eigenen Videocodec und entwickeln dazu von ihnen selbst gewählte optionale Erweiterungen, • bewerten die von ihnen realisierten Videocodecs durch einen subjektiven Vergleich, • reflektieren den Lernprozess während des Praktikums. * Learning Targets 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**	Das Praktikum Image and Video Compression wendet sich an Studierende aus den Studiengängen EEI, IuK und CE, die die Vorlesung Bild- und Videocodierung (Image and Video Coding) im gleichen Semester hören oder bereits gehört haben. The lab course Image and Video Compression is suited for students from the field of study in EEI, IuK, WIng, ASC, CME, and CE, who participate in the lecture Image and Video Compression in the current summer semester or who have already attended the lecture.
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**	
11	**Grading procedure**	
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**	Das Skriptum Praktikum Image and Video Compression wird in der Einführungsveranstaltung ausgegeben. The lab course notes will be distributed during the introductory meeting.

1	**Module name** 97535	**Laborpraktikum Statistische Signalverarbeitung**	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Walter Kellermann
5	**Contents**	After an introduction to scientific programming with Python, experiments and exercises related to the following topics are carried out during the laboratory course: Fundamental properties of random variables and stochastic processes Properties of correlations matrices, Principal Component Analysis (PCA), KLT Parametric and non-parametric linear signal models MMSE signal estimation Kalman filtering with applications to source tracking Optimum multichannel filtering Introduction to adaptive filtering. In the second phase of the lab course, the students will work in small project teams on relevant research problems. Nach einer Einführung in den Gebrauch der Programmiersprache Python werden Experimente und Übungen zu folgenden Themen der Statistischen Signalverarbeitung durchgeführt: • Grundlegende Eigenschaften von Zufallsvariablen und stochastischer Prozesse • Eigenschaften von Korrelationsmatrizen, Hauptachsentransformation, KLT • Parametrische und nicht-parametrische lineare Signalmodelle • MMSE-Signalschätzung • Kalman-Filterung mit Anwendungen zur Signalquellenverfolgung • Optimale Mehrkanalfilterung, • Einführung in die adaptive Filterung. In der zweiten Phase des Praktikums werden die Studenten in kleinen Projektgruppen (max. 3 Studenten) selbstständig eine forschungsrelevante Problemstellung analysieren und mögliche Lösungssansätze erarbeiten, implementieren und evaluieren.
6	**Learning objectives and skills**	The students implement Python codes to solve described problems and apply their collected knowledge, analyze, evaluate and discuss the implemented algorithms, familiarize themselves with the necessary steps to implement theoretical models, reflect their learning progress during the laboratory. Die Studenten

		• verfassen Python-Programme zu den einzelnen vorgezeichneten Experimenten und wenden damit das in Vorlesung und Übung erworbene Wissen an, • analysieren und evaluieren implementierte Algorithmen, • erlernen die notwendigen Schritte zur praktischen Umsetzung von theoretischen Modellen, • reflektieren ihren eigenen Lernprozess während des Praktikums.
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 Sensing & Perception - Seminar & Laboratory Master of Science Autonomy Technologies 20232
10	**Method of examination**	
11	**Grading procedure**	
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**	