UNIVERSITÄT ZU LÜBECK

Module Guide for the Study Path

Master Robotics and Autonomous Systems 2019

Version from 4. April 2024

interdisciplinary competence

advanced curriculum

Elective

Compulsory courses

Module part Current Issues Robotics and Automation

Additionally recognized elective module

EC5010-KP04, EC5010 - Entrepreneurship in the digital economy (EEntre)

Duration:	Turnus of offer:	Credit points:
1 Semester	each winter semester	4

Course of study, specific field and term:

- Master Entrepreneurship in Digital Technologies 2020 (compulsory), entrepreneurship, 3rd semester
- Master Media Informatics 2014 (optional subject), Interdisciplinary modules, Arbitrary semester
- Master Interdisciplinary Courses (optional subject), Interdisciplinary modules, Arbitrary semester
- Master Robotics and Autonomous Systems 2019 (optional subject), interdisciplinary competence, 1st or 2nd semester
- Master Entrepreneurship in Digital Technologies 2014 (compulsory), entrepreneurship, 3rd semester

Classes and lectures:

- Entrepreneurship in the digital economy (lecture, 2 SWS)
- Entrepreneurship in the digital economy (exercise, 1 SWS)

Workload:

- 60 Hours private studies
- 45 Hours in-classroom work
- 15 Hours exam preparation

Contents of teaching:

- In this class students obtain a key insight into the entrepreneurial processes, the identification of business opportunities as well as the shaping and changing of young companies. In addition, students are able to understand business models on a basic level. At the same time, this class will include strategy development, fundamental aspects of corporate marketing, growth forms and strategies, entrepreneurship in the context of established enterprises and social entrepreneurship.
- Special emphasize will be on start-ups in the digital economy.

Qualification-goals/Competencies:

- Students are able to identify the central issues in the process of founding a new company and have a broad Knowledge including the scientific basis as well as the practical application of the importance of entrepreneurship in economic and in a business context. Students are able to apply this knowledge to their own examples and in a changing context.
- Students are able to develop features and factors of successful start-ups and independently develop, visualize and submit business concepts based oncriteria and methods acquired. This knowledge is also linked to practicaland current topics and representable applications.
- Individual aspects of the event will be studied on selected case studies.
- Students master the scientific foundations and have specialized and in-depth expertise in innovation and technology management.
- Students know how to structure and solve problems even in new, unfamiliarand multidisciplinary contexts of innovation and technology management.
- Students are able to define goals for their own development and canreflect their own strengths and weaknesses, plan their individualdevelopment and reflect the societal impact.
- Students can work cooperatively and responsibly in groups and reflect and enhance their own cooperative behavior in groups critical.

Grading through:

- portfolio exam

Responsible for this module:

- Prof. Dr. Christian Scheiner

Teacher:

- Institute for Entrepreneurship and Business Development

- Prof. Dr. Christian Scheiner

Literature:

- Bygrave & Zacharakis: The Portable MBA in Entrepreneurship - Wiley-Verlag: 2010
- Bygrave & Zacharakis: Entrepreneurship - Wiley-Verlag: 3. Auflage 2013
- Hisrich, Peters & Shepherd: Entrepreneurship - McGraw-Hill: International Edition 2010

Language:

- English, except in case of only German-speaking participants

Notes:

Prerequisites for attending the module:
- none

Prerequisites for participation in module exam(s):
- none
- Prerequisites for admission to the (written) examination may be scheduled at the beginning of the semester. When prerequisites are defined, they should be completed and positively evaluated before the initial (written) examination.

Module exam(s):
- EC5010-L1: Entrepreneurship in the Digital Economy, portfolio exam, 100 % of module grade

The portfolio exam consists of the following:
- Group work(s) (Presentation), 40 %
- (Online)exams, 60 %

The commercial rounding is used to determine the overall grade.

Students for whom this course is a compulsory module have priority.

Registration takes place at the beginning of the semester via Moodle. Further questions related to registration and exam will be clarified during the first lectures.

(Formerly EC5010-KP04)

CS4503-KP12, CS4503 - Ambient Computing (AmbCompA)

Duration:	Turnus of offer:	Credit points:
2 Semester	normally each year in the summer semester	12

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (advanced module), advanced curriculum, Arbitrary semester
- Master Entrepreneurship in Digital Technologies 2020 (advanced module), technology field computer science, Arbitrary semester
- Master Computer Science 2019 (optional subject), advanced module, Arbitrary semester
- Master IT-Security 2019 (advanced module), Elective Computer Science, 1st or 2nd semester
- Master Entrepreneurship in Digital Technologies 2014 (advanced module), technology field computer science, 2nd and/or 3rd semester
- Master Computer Science 2014 (advanced module), advanced curriculum, 2nd and/or 3rd semester

Classes and lectures:

- CS4670 T: Ambient Computing (lecture, 3 SWS)
- Seminar Ambient Computing (seminar, 2 SWS)
- Lab Course Ambient Computing (project work, 3 SWS)

Workload:

- 120 Hours group work
- 120 Hours in-classroom work
- 70 Hours private studies
- 30 Hours oral presentation (including preparation)
- 20 Hours exam preparation

Contents of teaching:

- Ambient Computing:
- Current paradigms in computer technology
- Smart components
- Software architectures
- Context-sensitive systems
- Ambient Intelligence
- Interactive ambient media systems
- Ambient Computing Applications (AAL)
- Ethical, Legal and Social Implications (ELSI)

Qualification-goals/Competencies:

- Ambient Computing:
- The students are able to evaluate possibilities, concepts and challenges of Ambient Systems
- They have an overview about current technologies and systems for developing Ambient Systems
- They are able to follow and judge state-of-the-art research in the area of Ambient Computing

Grading through:

- portfolio exam

Responsible for this module:

- Prof. Dr.-Ing. Andreas Schrader

Teacher:

- Institute of Telematics

- Prof. Dr.-Ing. Andreas Schrader

Literature:

- John Krumm: Ubiquitous Computing Fundamentals - CRC Press, 2009
- Stefan Poslad: Ubiquitous Computing: Smart Devices, Environments and Interactions - Wiley, 2009
- Uwe Hansman et al: Pervasive Computing - Springer, 2003

Language:

- German and English skills required

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of the project assignment as specified at the beginning of the semester.
- Seminar lecture with elaboration according to the requirements at the beginning of the semester

Module Exam(s):
- CS4503-L1: Ambient Computing and Applications, Portfolio exam consisting of: 20 points in the form of a seminar paper with presentation, 20 points in the form of a project paper and 60 points in the form of an oral exam, 100% of module grade.

(Consists of CS4670 T)

CS4504-KP12, CS4504 - Cyber Physical Systems (CPS)

Duration:	Turnus of offer:	Credit points:
2 Semester	each year, can be started in winter or summer semester	12

Course of study, specific field and term:

- Master Entrepreneurship in Digital Technologies 2020 (advanced module), technology field computer science, Arbitrary semester
- Master Computer Science 2019 (optional subject), advanced module, Arbitrary semester
- Master Robotics and Autonomous Systems 2019 (advanced module), advanced curriculum, 1st or 2nd semester
- Master IT-Security 2019 (advanced module), Elective Computer Science, 1st or 2nd semester
- Master Entrepreneurship in Digital Technologies 2014 (advanced module), technology field computer science, 2nd and/or 3rd semester
- Master Computer Science 2014 (advanced module), advanced curriculum, 2nd and/or 3rd semester

Classes and lectures:

- CS5150 T: Organic Computing (lecture with exercises, 3 SWS)
- CS5153 T: Wireless Sensor Networks (lecture with exercises, 3 SWS)
- CS4504-S: Cyber Physical Systems (seminar, 2 SWS)

Workload:

- 220 Hours private studies
- 120 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- basic principles of organic computing / self-x system properties
- from motion to intelligent behavior and system/machine behavior
- design for self-organization, robustness, adaptivity, flexibility, trust
- analyzing, reverse-engineering, debugging machine behavior
- designing experiments and measuring behavior
- modeling system/machine behavior
- complexity, opacity, obscurity, trust of (AI) systems and explainable AI
- architecture of organic computing systems
- applications of self-x systems
- basics of wireless sensor networks
- hardware aspects of sensor nodes
- physics and protocols of wireless communication
- routing in wireless networks
- time synchronization and localization in wireless networks
- data management and data processing in wireless sensor networks
- applications of wireless sensor networks

Qualification-goals/Competencies:

- Students are able to utilize the principles of organic computing/self-x systems on exemplary designs.
- They are able to explain principles of organic computing/self-x systems.
- They are able to analyze system/machine behaviors in a structured, sound approach.
- Students are able to present the pros and cons of sensor networks.
- They are able to cope with analysis, design, and evaluation of protocols in sensor networks.
- They are able to interpret and pursue current research activities for sensor networks.

Grading through:

- Oral examination

Responsible for this module:

- Prof. Dr.-Ing. Mladen Berekovic

Teacher:

- Institute of Computer Engineering

- Dr. rer. nat. Javad Ghofrani

Literature:

- C. Müller-Schloer, S. Tomforde: Organic Computing Technical Systems for Survival in the Real World - Birkhäuser, 2017
- H. Karl, A. Willig: Protocols and Architectures of Wireless Sensor Networks - Wiley, 2005

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises as specified at the beginning of the semester.
- Seminar lecture and elaboration according to the requirements at the beginning of the semester

Module Exam(s):
- CS4504-L1: Cyber Physical Systems, oral exam, 100% of the module grade.

(Consists of CS5150 T, CS5153 T)

RO4500-KP12 - Advanced Control and Estimation (ACES)

Duration:	Turnus of offer:	Credit points:
2 Semester	each semester	12

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (advanced module), advanced curriculum, 1st and 2nd semester

Classes and lectures:

- Linear Systems Theory (lecture, 2 SWS)
- Linear Systems Theory (exercise, 2 SWS)
- Graphical Models in Systems and Control (lecture, 2 SWS)
- Graphical Models in Systems and Control (exercise, 1 SWS)
- Advanced Control and Estimation (seminar, 2 SWS)

Workload:

- 150 Hours private studies
- 150 Hours in-classroom work
- 30 Hours in-classroom exercises
- 30 Hours exam preparation

Contents of teaching:

- Content of teaching for course Linear Systems Theory:
- Vector spaces, norms, linear operators
- Eigenvalues, eigenvectors, Jordan normal form
- Singular value decomposition and operator norms
- Linear systems in continuous and discrete time
- Modeling of linear systems and linearization
- Fundamental solution to linear systems state equations
- Laplace transform and z-transform
- Content of teaching for course Graphical Models in Systems and Control:
- Introduction to Probability Theory, Discretely and Continuously Distributed Random Variables
- Fundamentals on Probabilistic Graphical Models
- Forney-Style Factor Graphs as a Probabilistic Graphical Model
- Message Passing via Sum- and Max-Produkt Algorithms
- Gaussian Message Passing
- State Estimation (Kalman Filtering and Smoothing including Nonlinear Extensions)
- Parameter Estimation via Expectation Maximization
- Expectation Propagation
- Control on Factor Graphs
- Content of teaching of the seminar Advanced Control and Estimation:
- Current state of the art algorithms in stochastic signal processing, estimation, identification and control.

Qualification-goals/Competencies:

- Educational objectives for course Linear Systems Theory:
- Students are familiar with the important basic concepts of linear algebra.
- Students have a solid background in the theory of linear systems in continuous and disrete time.
- Students are able to model linear systems in mechanical and electrical domain from first principles.
- Students are able to solve the state equations and analyze systems in the time and frequency domain.
- Students improve their problem solving and mathematical skills.
- Students develop their techniques for logical reasoning and and rigorous proofs.
- Students are enabled to perform reseaerch in the field of systems and control theory.
- Educational objectives for course Graphical Models in Systems and Control:
- Students develop and extend their fundamental knowledge on probability theory and the transformation of discretely as well as continuously distributed random variables.
- Students can understand simple linear algorithms, such as the Kalman filter, with the help of graphical probabilistic models.
- Students can combine elements of probabilistic algorithms to novel ones with the help of graphical probabilistic models.
- Students can understand, extend and apply advanced algorithms in signal processing, parameter and state estimation as well as control to relevant problems with the help of graphical probabilistic models.
- Educational objectives of the seminar Advanced Control and Estimation:
- Students are able to research and understand current literature.
- Students are able to reproduce and evaluate current algorithms based on research literature.
- Students are able reproduce, extend and present results from current research literature.

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr. Philipp Rostalski
- Prof. Dr. Georg Schildbach

Teacher:

- Institute for Electrical Engineering in Medicine

- Prof. Dr. Georg Schildbach
- Prof. Dr.-Ing. Christian Herzog

Literature:

- Loeliger, Hans-Andrea; Dauwels, Justin; Hu, Junli; Korl, Sascha; Ping, Li; Kschischang, Frank R.: The Factor Graph Approach to Model-Based Signal Processing - Proc. IEEE, Vol. 95, No. 6, 2007
- Loeliger, Hans-Andrea: An Introduction to factor graphs - IEEE Signal Process. Mag., Vol. 21, No. 1, 2004
- Hoffmann, Christian; Rostalski, Philipp: Current Publications from Research at the IME
- Miscellaneous: Current Publications from Research

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises as specified at the beginning of the semester.

Module Exam(s):
- RO4500-L1: Advanced Control and Estimation, One oral examination on the contents of both submodules, 40min, 100% of the module grade.
- RO4500-S: Seminar Advanced Control and Estimation, must be passed

RO5100-KP12 - Medical Robotics (MedRob12)

Duration:	Turnus of offer:	Credit points:
2 Semester	each year, can be started in winter or summer semester	12

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (advanced module), advanced curriculum, 1st or 2nd semester

Classes and lectures:

- Inverse Problems in Image Processing (lecture, 2 SWS)
- Inverse Problems in Image Processing (exercise, 1 SWS)
- Medical Robotics (lecture, 2 SWS)
- Medical Robotics (exercise, 1 SWS)
- Seminar Robotics und Automation (seminar, 2 SWS)

Workload:

- 190 Hours private studies
- 150 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Introduction to inverse and ill-posed problems on the basis of selected examples (including seismology, impedance tomography, heat conduction, computed tomography, acoustics)
- Concept of ill-posedness of the inverse problem (Hadamard)
- Singular value decomposition and generalized inverse
- Regularization methods (eg Tikhonov, Phillips, Ivanov)
- Deconvolution
- Image restoration (deblurring, defocusing)
- Statistical methods (Bayes, maximum likelihood)
- Computed Tomography, Magnetic Particle Imaging

Qualification-goals/Competencies:

- Students are able to explain the concept of ill-posedness of the inverse problem and distinguish given inverse problems regarding good or bad posedness.
- They are able to formulate inverse problems of mathematical imaging and solve (approximate) with suitable numerical methods.
- They can assess the condition of a problem and the stability of a method.
- They master different regularization methods and are able to apply them to practical problems.
- They know methods to determine a suitable regularization.
- They can use methods of image reconstruction and restoration on real measurement data.
- Students are able to explain the concepts of forward and inverse kinematics for the examples of 3-joint and 6-joint robots.
- They are able to apply methods of medical robot systems and to simple practical applications.
- Students are able to transfer methods of motion learning to simple practical problems.
- Students are able to modify templates for dynamic calculations in order to create the calculations for their own constructions.

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr.-Ing. Achim Schweikard

Teacher:

- Institute of Computer Engineering
- Institute for Electrical Engineering in Medicine
- Institute of Medical Engineering
- Institute of Medical Informatics
- Institute for Robotics and Cognitive Systems

Literature:

- Kak and Slaney: Principles of Computerized Tomographic Imaging - SIAM Series 33, New York, 2001
- Natterer and Wübbeling: Mathematical Methods in Image Reconstruction - SIAM Monographs, New York 2001
- Bertero and Boccacci: Inverse Problems in Imaging - IoP Press, London, 2002
- Andreas Rieder: Keine Probleme mit inversen Problemen - Vieweg, Wiesbaden, 2003
- Buzug: Computed Tomography - Springer, Berlin, 2008

- J. -C. Latombe: Robot Motion Planning - Dordrecht: Kluwer 1990
- J.J. Craig: Introduction to Robotics - Pearson Prentice Hall 2002
- : Vorlesungsskript: Med. Robotics

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercise assignments as specified at the beginning of the semester

Module Exam(s):
- RO5100-L1: Medical Robotics, one oral examination on the contents of both submodules, 100% of the module grade
- CS5280-S: Seminar Robotics and Automation, must be passed

RO5200-KP12 - Bio-inspired Robotics (BR)

Duration:	Turnus of offer:	Credit points:
2 Semester	each year, can be started in winter or summer semester	12

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (advanced module), advanced curriculum, Arbitrary semester

Classes and lectures:

- Collective Robotics (lecture, 2 SWS)
- Collective Robotics (exercise, 1 SWS)
- Evolutionary Robotics (lecture, 2 SWS)
- Evolutionary Robotics (exercise, 1 SWS)
- Seminar Bio-inspired Robotics (seminar, 2 SWS)

Workload:

- 220 Hours private studies
- 120 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Biological basics
- Self-organization, robustness, scalability, superlinear speedups
- Robot swarms by land, by sea, and by air
- Mathematical modeling of swarms and collective decision-making
- Evolutionary computation
- Artificial evolution of robot controllers and robot morphologies
- Optimization and learning in robot experiments
- Independent familiarization with an area of service robotics based on technical literature
- Writing and presentation of an own scientific paper

Qualification-goals/Competencies:

- Students get a comprehensive overview of biologically inspired.
- Students are able to assess chances and challenges of robust and scalable robot systems.
- Students are able to implement reactive control for swarm robots in simulation and on mobile robots.
- Students are able to implement evolutionary algorithms and artificial neural networks and are able to apply them to problems of mobile robots in.
- Students are able to name challenges of evolutionary robotics in applications and to discuss potential solutions.
- Die Teilnehmer sind in der Lage, eine wissenschaftliche Arbeit eigenständig zu verfassen und vorzutragen.
- The students are able to investigate self-dependently scientific publications, to analyze and understand their contents.
- The participants can analyze and reproduce the tenor with regard to their scope of work. The students are competent to write and present their own scientific work.

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr.-Ing. Mladen Berekovic

Teacher:

- Institute of Computer Engineering

- Dr. rer. nat. Javad Ghofrani

Literature:

- Nolfi, S., Floreano, D.: The Biology, Intelligence, and Technology of Self-Organizing Machines - MIT Press, 2001
- Hamann, H.: Swarm Robotics: A Formal Approach - Springer 2018

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises of both sub-modules as specified at the beginning of the respective semester.

Module Exam(s):
- RO5200-L1: Bio-inspired Robotics, oral examination on the contents of both submodules, 2/3 of the module grade
- RO5200-S: Seminar Bio-inspired Robotics, 1/3 of the module grade

RO5500-KP12 - Autonomous Vehicles (AVS)

Duration:	Turnus of offer:	Credit points:
2 Semester	starts every winter semester	12

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (advanced curriculum), advanced curriculum, 1st and 2nd semester

Classes and lectures:

- Vehicle Dynamics and Control (lecture, 2 SWS)
- Vehicle Dynamics and Control (exercise, 2 SWS)
- Perception for Autonomous Vehicles (lecture, 2 SWS)
- Perception for Autonomous Vehicles (exercise, 2 SWS)
- Technology of Autonomous Vehicles (seminar, 2 SWS)

Workload:

- 220 Hours private studies
- 80 Hours in-classroom work
- 60 Hours exam preparation

Contents of teaching:

- Content of teaching of the course Vehicle Dynamics and Control:
- Review of control methods and rigid body dynamics
- Basic terminology of vehicle dynamics
- Vehicle dynamic models (lateral, longitudinal, vertical)
- Component models (engine, transmission, brake, steering)
- Tire modeling
- Stability analysis
- Handling performance
- Active safety systems
- Autonomous driving
- Content of teaching of the course Perception for Autonomous Driving:
- The architecture of autonomous-driving systems
- Tracking, detection, classification
- Models of stochastic signals
- Transform-based analysis of stochastic signals
- System theory
- Parameter estimation
- Linear optimal filters and adaptive filters
- Graphical models and dynamic Bayes networks
- Neural networks
- Hidden Markov Models, Kalman Filter, Particle Filter, etc.
- Applications in the domain of autonomous driving
- Content of teaching of the seminar Current Topics in Autonomous Vehicles:
- Current algorithms in machine learning and artificial intelligence related to autonomous driving

Qualification-goals/Competencies:

- Educational objectives of the course Vehicle Dynamics and Control:
- Students master basic terminology and concepts of vehicle dynamics.
- Students obtain a comprehensive understanding of the dynamics of a vehicle.
- Students understand the main objectives of vehicle control.
- Students can derive basic vehicle dynamics models for control design.
- Students are able to apply concepts of basic and advanced control and estimation to practical problems.
- Students get an insight into the field of active safety systems, driver assistance, and autonomous driving.
- Students are able to perform independent design, research and development work in this field.
- Educational objectives of the course Perception for Autonomous Driving:
- Students get an overview on autonomous-driving systems.
- Students become thoroughly acquainted with the perception layer of the architecture of an autonomous-driving system.
- Students get a comprehensive introduction to stochastic signals.
- Students master tools for the analysis of stochastic signals.
- Students are able to make use of various models for stochastic signals.
- Students are able to design tracking algorithms.
- Students are able devise algorithmic solutions to decision problems, while making use of prior knowledge.
- Educational objectives of the seminar Current Topics in Autonomous Vehicles:

- Students are able to research and understand current literature.
- Students are able to reproduce and evaluate current algorithms based on research literature.
- Students are able reproduce, extend and present results from current research literature.

Grading through:

- Written or oral exam as announced by the examiner

Requires:

- Control Systems (RO4400-KP08)
- Technical Mechanics (RO1500-KP08)

Responsible for this module:

- Prof. Dr. Georg Schildbach

Teacher:

- Institute for Electrical Engineering in Medicine

- Prof. Dr. Georg Schildbach
- PD Dr.-Ing. habil. Alexandru Paul Condurache

Literature:

- Rajamani, R: Vehicle Dynamics and Control (2nd edition) - Springer, 2012, ISBN 978-1-4614-1432-2
- Mitschke, M; Wallentowitz, H.: Dynamik der Kraftfahrzeuge (5th edition) - Springer, 2014 (ISBN: 978-3-658-05067-2)
- Charles W. Therrien: Decision estimation and classification - J. Wiley and Sons, 1991.
- Simon Haykin: Adaptive Filter Theory - Prentice Hall, 1996
- Christopher M. Bishop: Pattern recognition and machine learning - Springer, 2006
- A. Mertins: Signaltheorie: Grundlagen der Signalbeschreibung, Filterbänke, Wavelets, Zeit-Frequenz-Analyse, Parameter- und Signalschätzung - Springer-Vieweg, 3. Auflage, 2013

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises as specified at the beginning of the semester.

Module Examination(s):
- RO5500-L1: Vehicle Dynamics and Control, written exam, 60min, 50% of module grade
- RO5500-L2: Perception for Autonomous Vehicles, written exam, 60min, 50% of the module grade
- RO5500-L3 Technology of Autonomous Vehicles; Seminar; ungraded; 0% of module grade, must be passed

RO5800-KP12 - Advanced Topics in Robotics (ATRS)

Duration:	Turnus of offer:	Credit points:
2 Semester	each year, can be started in winter or summer semester	12

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (advanced curriculum), advanced curriculum, 1st or 2nd semester

Classes and lectures:

- Advanced Topics in Robotics (lecture, 2 SWS)
- Advanced Topics in Robotics (exercise, 1 SWS)
- Rescue Robotics (lecture, 2 SWS)
- Rescue Robotics (exercise, 2 SWS)
- Machine Learning in Medicine (seminar, 2 SWS)

Workload:

- 135 Hours in-classroom work
- 95 Hours private studies
- 90 Hours work on an individual topic with written and oral presentation or group work
- 40 Hours exam preparation

Contents of teaching:

- Content of teaching of the course Advanced Topics in Robotics:
- Motion Planning for Robots
- Augmented Reality
- Design of Robot Systems
- Intracorporal Robotics
- Dynamics and Control of Robots
- Content of teaching of the course Rescue Robotics:
- Special requirements for disaster management and response and the resulting consequences on rescue robot design.
- Information structures for rescue systems
- Information exchange between rescue robots
- Command and control systems for search and rescue robots
- Tactical communication for cooperative SAR robot missions as well as interoperability in heterogeneous teams.
- Design guidelines for human interfaces to rescue robots
- Casualty and vital sign detection in rescue scenarios
- Medical assistance at the scene of incident and determination of vital signs
- Evaluation and benchmarking of SAR robots
- Content of teaching of the seminar Machine Learning in Medicine:
- Access to a scientific field
- Work towards a scientific solution to a problem with appropriate methods
- Presentations and discussions in English
- Possible topics: Computer Aided Diagnosis, Gaussian Processes for Sensor Data Analysis, Motion Prediction, Correlation Methods for Motion Estimation, Tissue Thickness Estimation, Sensor Calibration

Qualification-goals/Competencies:

- Educational objectives of the course Advanced Topics in Robotics:
- Students understand the connection to underlying mathematical methods, especially in dynamics, optimization, and sensor data processing and analysis of algorithms.
- Students have an extended overview of application areas for robotics.
- They are able to implement such methods and derive new applications based on such methods.
- Educational objectives of the course Rescue Robotics:
- The students can apply the tools to program and simulate mobile rescue robots. They have developed a good overview about mobile robotics, localization and path planning in difficult scenarios.
- The students have knowledge about the work and command structures of rescue personell and the requirements on control, communcation and interaction of rescue robots with the personnel.
- The students have developed a notion of medical first response by rescue personnel as well as technical solutions to locate missing persons, determine vital signs and realize medical assistance at the scene of incident.
- Educational objectives of the course Seminar Machine Learning in Medicine:
- The students can analyze, develop and evaluate a research topic.
- The students can comprehensibly present research results in written or spoken presentations.
- The students can elaborate on a scientific field in the English language.
- The students can frame a topic within the scientific context.

Grading through:

- written exam, oral exam and/or presentation as announced by the examiner

Requires:

- Robotics (CS2500-KP04, CS2500)

Responsible for this module:

- Prof. Dr.-Ing. Achim Schweikard

Teacher:

- Institute for Robotics and Cognitive Systems

- Prof. Dr.-Ing. Achim Schweikard
- Prof. Dr. rer. nat. Floris Ernst

Literature:

- Achim Schweikard, Floris Ernst: Medical Robotics - Springer, 2015, Jocelyne Troccaz (ed.): Medical Robotics, Wiley, 2009
- Tadokoro, Satoshi, ed.: Rescue robotics: DDT project on robots and systems for urban search and rescue. - Springer Science & Business Media, 2009. (ISBN: 978-1447157656).
- Siciliano, Bruno, and Oussama Khatib, eds.: Springer handbook of robotics. - Springer, 2016. (ISBN: 978-3319325507)

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None (the competencies of the modules listed under competencies)

CS4130-KP06, CS4130 - Information Systems (InfoSys)

Duration:	Turnus of offer:	Credit points:
1 Semester	each summer semester	6

Course of study, specific field and term:

- Master Computer Science 2019 (compulsory), Canonical Specialization Data Science and AI, Arbitrary semester
- Master Entrepreneurship in Digital Technologies 2020 (basic module), technology field computer science, 1st or 2nd semester
- Master Media Informatics 2020 (optional subject), computer science, Arbitrary semester
- Master Computer Science 2019 (basic module), Applied computer science, 1st or 2nd semester
- Master Medical Informatics 2019 (basic module), Applied computer science, 1st or 2nd semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 1st or 2nd semester
- Master IT-Security 2019 (basic module), Applied computer science, 1st or 2nd semester
- Master Medical Informatics 2014 (basic module), ehealth / infomatics, 1st or 2nd semester
- Master Media Informatics 2014 (optional subject), computer science, Arbitrary semester
- Master Entrepreneurship in Digital Technologies 2014 (basic module), technology field computer science, 1st or 2nd semester
- Master Computer Science 2014 (optional subject), specialization field software systems engineering, 2nd or 3rd semester
- Master Computer Science 2014 (basic module), Applied computer science, 1st or 2nd semester

Classes and lectures:

- Information Systems (lecture, 2 SWS)
- Information Systems (exercise, 2 SWS)

Workload:

- 100 Hours private studies
- 60 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Motivation of knowledge graphs and their relationship to the Semantic Web
- Overview over the W3C Semantic Web family of languages
- Comparison between and the interaction of knowledge graphs and generative artificial intelligence such as large language models
- Graph Neural Networks and their applications for tasks of knowledge graphs

Qualification-goals/Competencies:

- Knowledge: Students acquire an overview of knowledge graphs and the Semantic Web as well as generative artificial intelligence such as large language models and graph neural networks.
- Skills: Students can assess the possibilities and limitations of knowledge graphs and the Semantic Web. They can estimate the consequences of the Semantic Web approach for data modeling, data administration and processing and for applications. They can develop Semantic Web applications. They can use generative artificial intelligence such as large language models and graph neural networks to solve tasks for and in addition to knowledge graphs. They can discuss open research questions in the area of knowledge graphs and the semantic web as well as in comparison to generative artificial intelligence and graph neural networks.
- Social skills and independence: Students work in groups to complete exercises and small projects. Students' independent practical work is encouraged through exercises, some of them directly on the computer.

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr. Sven Groppe

Teacher:

- Institute of Information Systems

- Prof. Dr. Sven Groppe

Literature:

- M. Kejriwal, C. Knoblock: Knowledge graphs - MIT Press, 2021
- S. Groppe: Data Management and Query Processing in Semantic Web Databases - Springer, 2011
- W. L. Hamilton: Graph Representation Learning. In Synthesis Lectures on Artificial Intelligence and Machine Learning - Springer International Publishing, 2020
- D. Jurafsky, J. H. Martin: Speech and language processing - Upper Saddle River, NJ: Pearson, 2008
- D. Foster: Generative deep learning - Sebastopol, CA: O Reilly Media, 2023

Language:

- German and English skills required

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises as specified at the beginning of the semester

Module Exam(s):
- CS4130-L1: Information Systems, written exam or oral exam, 100% of module grade

Previous name: Web Based Information Systems

CS4150-KP06, CS4150SJ14 - Distributed Systems (VertSys14)

Duration:	**Turnus of offer:**	**Credit points:**
1 Semester	each winter semester	6

Course of study, specific field and term:

- Master Computer Science 2019 (compulsory), Canonical Specialization SSE, Arbitrary semester
- Master Entrepreneurship in Digital Technologies 2020 (basic module), technology field computer science, 1st or 2nd semester
- Master Media Informatics 2020 (optional subject), computer science, Arbitrary semester
- Master Computer Science 2019 (basic module), Applied computer science, 1st or 2nd semester
- Master Medical Informatics 2019 (basic module), Applied computer science, 1st or 2nd semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 1st or 2nd semester
- Master IT-Security 2019 (basic module), Applied computer science, 1st or 2nd semester
- Master Medical Informatics 2014 (basic module), ehealth / infomatics, 1st or 2nd semester
- Master Media Informatics 2014 (optional subject), computer science, Arbitrary semester
- Master Entrepreneurship in Digital Technologies 2014 (basic module), technology field computer science, 1st or 2nd semester
- Master Computer Science 2014 (optional subject), specialization field software systems engineering, 2nd or 3rd semester
- Master Computer Science 2014 (basic module), Applied computer science, 1st or 2nd semester

Classes and lectures:

- Distributed Systems (lecture, 2 SWS)
- Distributed Systems (exercise, 2 SWS)

Workload:

- 60 Hours private studies
- 60 Hours in-classroom work
- 40 Hours e-learning
- 20 Hours exam preparation

Contents of teaching:

- Introduction and motivation
- Protocols and layered models
- Message representations
- Realization of network services
- Communication mechanisms
- Addresses, names and directory services
- Synchronisation
- Replication and consistency
- Fault tolerance
- Distributed transactions
- Security

Qualification-goals/Competencies:

- The participants will accquire a deep understanding for problems to be solved in distributed systems, such as synchronization, error handling, naming etc.
- They know the most important services in distributed systems such as name service, distributed file systems etc.
- They are able to program simple distributed applications and systems themselves.
- They know the most important algorithms in distributed systems, for instance for time synchronization, for leader election, or for mutual exclsuion.
- They have a good feeling for when it makes sense to use distributed instead of centralized systems.
- They have a good feeling for what kind of solutions could best be used for what kind of problems in distributed Internet applications.

Grading through:

- written exam

Responsible for this module:

- Prof. Dr. Stefan Fischer

Teacher:

- Institute of Telematics

- Prof. Dr. Stefan Fischer
- Dr. rer. nat. Florian-Lennert Lau

Literature:

- A. Tanenbaum, M. van Steen: Distributed Systems: Principles and Paradigms - Prentice Hall 2006
- G. Coulouris, J. Dollimore, T. Kindberg, G. Blair: Distributed Systems - Concepts and Design - Addison Wesley 2012

Language:

- offered only in German

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- None

Module Exam(s):
- CS4150-L1 Distributed Systems, written exam, 90min, 100% of module grade.

CS4170-KP06, CS4170SJ14 - Parallel Computer Systems (ParaRSys14)

Duration:	Turnus of offer:	Credit points:
1 Semester	each winter semester	6

Course of study, specific field and term:

- Certificate in Artificial Intelligence (compulsory), Artificial Intelligence, 1st semester
- Master Entrepreneurship in Digital Technologies 2020 (advanced module), technology field computer science, Arbitrary semester
- Master Computer Science 2019 (basic module), technical computer science, 1st or 2nd semester
- Master Medical Informatics 2019 (optional subject), technical computer science, 1st or 2nd semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 1st or 2nd semester
- Master IT-Security 2019 (basic module), technical computer science, 1st or 2nd semester
- Master Medical Informatics 2014 (basic module), computer science, 1st or 2nd semester
- Master Entrepreneurship in Digital Technologies 2014 (basic module), technology field computer science, 1st or 2nd semester
- Master Computer Science 2014 (basic module), technical computer science, 1st or 2nd semester

Classes and lectures:

- Parallel Computer Systems (lecture, 2 SWS)
- Parallel Computer Systems (exercise, 2 SWS)

Workload:

- 100 Hours private studies
- 60 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Motivation and limitations for parallel processing
- Parallel computing models
- Taxonomy of parallel computers
- Multi/manycore-systems
- Graphic Processing Units (GPUs)
- OpenCL
- Specification languages
- Hardware architectures
- System management of many-core systems

Qualification-goals/Competencies:

- Students are able to characterize different parallel computing architectures.
- They are able to explain models of parallel computing.
- They are able to make use of common programming interfaces for parallel computing systems.
- They are able to judge which kind of parallel computing system is best suited for a dedicated problem and how many cores should be used.
- They are able to evaluate the pros and cons of different hardware architectures.
- They are able to write programs for parallel computing systems under considerations of the underlying hardware architecture.
- They are able to compare methods for dynamic voltage and frequency scaling (DVFS) for manycore systems.

Grading through:

- written exam

Responsible for this module:

- Prof. Dr.-Ing. Mladen Berekovic

Teacher:

- Institute of Computer Engineering

- Prof. Dr.-Ing. Mladen Berekovic

Literature:

- G. Bengel, C. Baun, M. Kunze, K. U. Stucky: Masterkurs Parallele und Verteilte Systeme - Vieweg + Teubner, 2008
- M. Dubois, M. Annavaram, P. Stenström: Parallel Computer Organization and Design - University Press 2012
- B. R. Gaster, L. Howes, D. R. Kaeli, P. Mistry, D. Schaa: Heterogeneous Computing with OpenCL - Elsevier/Morgan Kaufman 2013
- B. Wilkinson; M. Allen: Parallel Programming - Englewood Cliffs: Pearson 2005
- J. Jeffers, J. Reinders: Intel Xeon Phi Coprozessor High-Performance Programming - Elsevier/Morgan Kaufman 2013

- D. A. Patterson, J. L. Hennessy: Computer Organization and Design - Morgan Kaufmann, 2013

Language:

- offered only in German

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercise assignments as specified at the beginning of the semester

Module Exam(s):
- CS4170-L1: Parallel Computer Systems, oral exam, 100% of the module grade

CS4220-KP04, CS4220 - Pattern Recognition (Muster)

Duration:	Turnus of offer:	Credit points:
1 Semester	not available anymore	4

Course of study, specific field and term:

- Master MES 2020 (optional subject), medical engineering science, Arbitrary semester
- Master Media Informatics 2020 (optional subject), computer science, Arbitrary semester
- Master MES 2014 (optional subject), medical engineering science, Arbitrary semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 1st or 2nd semester
- Master CLS 2016 (compulsory), mathematics, 2nd semester
- Master Medical Informatics 2019 (optional subject), Medical Data Science / Artificial Intelligence, 1st or 2nd semester
- Master Medical Informatics 2014 (optional subject), medical image processing, 1st or 2nd semester

Classes and lectures:

- Pattern Recognition (lecture, 2 SWS)
- Pattern Recognition (exercise, 1 SWS)

Workload:

- 55 Hours private studies
- 45 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Introduction to probability theory
- Principles of feature extraction and pattern recognition
- Bayes decision theory
- Discriminance functions
- Neyman-Pearson test
- Receiver Operating Characteristic
- Parametric and nonparametric density estimation
- kNN classifiers
- Linear classifiers
- Support vector machines and kernel trick
- Random Forest
- Neural Nets
- Feature reduction and feature transforms
- Validation of classifiers
- Selected application scenarios: acoustic scene classification for the selection of hearing-aid algorithms, acoustic event recognition, attention classification based on EEG data, speaker and emotion recognition

Qualification-goals/Competencies:

- Students are able to describe the main elements of feature extraction and pattern recognition.
- They are able to explain the basic elements of statistical modeling.
- They are able to use feature extraction, feature reduction and pattern classification techniques in practice.

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr.-Ing. Alfred Mertins

Teacher:

- Institute for Signal Processing

- Prof. Dr.-Ing. Alfred Mertins

Literature:

- R. O. Duda, P. E. Hart, D. G. Storck: Pattern Classification - New York: Wiley

Language:

- offered only in German

Notes:

Prerequisites for attending the module:
- None

Prerequisites for the exam:
- Successful completion of homework assignments during the semester (at least 50% of max. points) and successful project task.

Modul exam:
- CS4220-L1:Pattern Recognition, written exam, 90 Min, 100% of modul grade

CS4290-KP04, CS4290 - Current Issues Robotics and Automation (RobAktuell)

Duration:	Turnus of offer:	Credit points:
1 Semester	each semester	4

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 1st and/or 2nd semester
- Master Computer Science 2014 (compulsory), specialization field robotics and automation, 2nd or 3rd semester

Classes and lectures:

- CS4660-KP04: Process Control Systems (lecture with exercises, 3 SWS)
- CS5275 T: Selected Topics of Signal Analysis and Enhancement (lecture with exercises, 3 SWS)
- CS5280 T: Seminar Robotics and Automation (seminar, 2 SWS)
- RO4210-KP04: Path Planning and Control of Wheeled Robots (PPaCWR) (lecture with exercises, 3 SWS)

Workload:

- 60 Hours private studies
- 45 Hours in-classroom work
- 15 Hours exam preparation

Contents of teaching:

- see module parts

Qualification-goals/Competencies:

- see module parts

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr. Philipp Rostalski

Teacher:

- Institute for Electrical Engineering in Medicine
- Institute for Multimedia and Interactive Systems
- Institute for Signal Processing
- Institute for Robotics and Cognitive Systems
- Institute of Computer Engineering

Literature:

- see module parts:

Language:

- German and English skills required

Notes:

One of the listed submodules amounting to 4 ECTS must be chosen.

Admission requirements for taking the module:
- See selected module

Admission requirements for participation in module examination(s):
- See selected module

Module Exam(s):
- CS4290-L1: Current Issues Robotics and Automation, see selected module

CS4374-KP06 - Medical Deep Learning (MDL)

Duration:	Turnus of offer:	Credit points:
1 Semester	each summer semester	6

Course of study, specific field and term:

- Master MES 2020 (optional subject), computer science / electrical engineering, Arbitrary semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 1st or 2nd semester
- Master Medical Informatics 2014 (optional subject), medical computer science, 1st or 2nd semester
- Master MES 2014 (optional subject), computer science / electrical engineering, 1st or 2nd semester
- Master Medical Informatics 2019 (advanced module), medical computer science, 1st or 2nd semester

Classes and lectures:

- Medical Deep Learning (lecture, 2 SWS)
- Medical Deep Learning (exercise, 2 SWS)

Workload:

- 80 Hours private studies
- 60 Hours in-classroom work
- 40 Hours exam preparation

Contents of teaching:

- Cardiac Healthcare:
- ECG signal analysis for arrhythmia detection or sleep apnea and for mobile low-cost devices
- MRI sequence analysis for anatomical segmentation and temporal modelling
- Multimodal Clinical Case Retrieval / Prediction:
- Pathology and Semantic Image Retrieval and Localisation
- Analysis of text / natural language (radiology reports/study articles) for multimodal data mining in Electronic Health Records (EHR)
- Computer Aided Detection and Disease Classification:
- CT Lung nodule detection for cancer screening with data augmentation and transfer learning
- Weakly-supervised abnormality detection and biomarker discovery
- Interpretable and reliable deep learning systems
- Human interaction and correction within deep learning models
- Visualisation of uncertainty and internally learned representations
- Deep Learning Concepts, Architectures and Hardware
- Convolutional Neural Networks, Layers, Deep Residual Learning
- Losses, Derivatives, Large-scale Stochastic Optimisation
- Directed Acyclic Graph Networks, Generative Adversarial Networks
- Cloud Computing, GPUs, Low Precision Computing, DL Frameworks

Qualification-goals/Competencies:

- Students know the importance of data security, patient anonymisation and ethics for clinical studies involving sensitive data
- They know methods and tools to collect, preprocess, store and annotate large datasets for deep learning from medical data
- They have an in-depth understanding of deep / convolutional neural networks for general data (signals / text / images) processing, their learning process and evaluation of their performance on unseen data
- They understand the principles of weakly-supervised learning, transfer learning, concept discovery and generative adversarial networks
- They know how to explore learned feature representations for retrieval and visualisation of high-dimensional abstract data
- They can implement modern network architectures in DL frameworks and are able to adapt and extend them to given problems in medicine
- They have a broad overview of current applications of deep learning in medicine in both research and clinical practice and can transfer their knowledge to newly emerging domains

Grading through:

- Oral examination

Responsible for this module:

- Prof. Dr. Mattias Heinrich

Teacher:

- Institute of Medical Informatics

- Prof. Dr. Mattias Heinrich

Literature:

- Ian Goodfellow, Yoshua Bengio and Aaron Courville: Deep Learning - The MIT Press

Language:

- English, except in case of only German-speaking participants

Notes:

Admission requirements for taking the module:
- None

Admission requirements for taking module examination(s):
- Successful completion of exercise assignments and programming tasks as specified at the beginning of the semester.

Module Exam(s):
- CS4374-L1 Medical Deep Learning, , oral examination.

CS4405-KP04, CS4405 - Neuroinformatics (NeuroInf)

Duration:	Turnus of offer:	Credit points:
1 Semester	each summer semester	4

Course of study, specific field and term:

- Master CLS 2023 (compulsory), computer science, 2nd semester
- Master Auditory Technology 2022 (optional subject), Auditory Technology, 2nd semester
- Master Auditory Technology 2017 (optional subject), Auditory Technology, 2nd semester
- Master MES 2020 (optional subject), computer science / electrical engineering, Arbitrary semester
- Master CLS 2016 (compulsory), computer science, 2nd semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 1st or 2nd semester
- Master MES 2014 (optional subject), computer science / electrical engineering, Arbitrary semester
- Master MES 2011 (optional subject), mathematics, 2nd semester
- Bachelor MES 2011 (optional subject), optional subject medical engineering science, 6th semester
- Master Computer Science 2012 (optional subject), advanced curriculum organic computing, 2nd or 3rd semester
- Master MES 2011 (advanced curriculum), imaging systems, signal and image processing, 2nd semester
- Master Computer Science 2012 (optional subject), advanced curriculum intelligent embedded systems, 2nd or 3rd semester
- Master Computer Science 2012 (compulsory), specialization field robotics and automation, 2nd semester
- Master Computer Science 2012 (compulsory), specialization field bioinformatics, 2nd semester
- Master CLS 2010 (compulsory), computer science, 2nd semester

Classes and lectures:

- Neuroinformatics (lecture, 2 SWS)
- Neuroinformatics (exercise, 1 SWS)

Workload:

- 55 Hours private studies
- 45 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- The human brain and abstract neuron models
- Learning with a single neuron:* Perceptrons* Max-Margin Classification* LDA and logistic Regression
- Network architectures:* Hopfield-Networks* Multilayer-Perceptrons* Deep Learning
- Unsupervised Learning:* k-means, Neural Gas and SOMs* PCA & ICA* Sparse Coding

Qualification-goals/Competencies:

- The students are able to understand the principle function of a single neuron and the brain as a whole.
- They know abstract neuronal models and they are able to name practical applications for the different variants.
- They are able to derive a learning rule from a given error function.
- They are able to apply (and implement) the proposed learning rules and approaches to solve unknown practical problems.

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr. rer. nat. Thomas Martinetz

Teacher:

- Institute for Neuro- and Bioinformatics

- Prof. Dr. rer. nat. Thomas Martinetz
- Prof. Dr. rer. nat. Amir Madany Mamlouk

Literature:

- S. Haykin: Neural Networks - London: Prentice Hall, 1999
- J. Hertz, A. Krogh, R. Palmer: Introduction to the Theory of Neural Computation - Addison Wesley, 1991
- T. Kohonen: Self-Organizing Maps - Berlin: Springer, 1995
- H. Ritter, T. Martinetz, K. Schulten: Neuronale Netze: Eine Einführung in die Neuroinformatik selbstorganisierender Netzwerke - Bonn: Addison Wesley, 1991

Language:

- offered only in German

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises as specified at the beginning of the semester

Module Exam(s):
- CS4405-L1: Neuroinformatics, written exam, 90 min, 100% of module grade

According to the old version of the MES Bachelor Examination Regulations (until WS 2011/2012), an elective subject is scheduled for the 4th semester instead of the 6th semester.

CS5170-KP04, CS5170 - Hardware/Software Co-Design (HWSWCod)

Duration:	Turnus of offer:	Credit points:
1 Semester	each winter semester	4

Course of study, specific field and term:

- Master Computer Science 2019 (compulsory), Canonical Specialization SSE, Arbitrary semester
- Master Computer Science 2019 (optional subject), Elective, Arbitrary semester
- Master Media Informatics 2020 (optional subject), computer science, Arbitrary semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 1st or 2nd semester
- Master Computer Science 2014 (compulsory), specialization field software systems engineering, 1st or 2nd semester
- Master MES 2011 (advanced curriculum), imaging systems, signal and image processing, 1st or 3rd semester
- Master Media Informatics 2014 (optional subject), computer science, Arbitrary semester
- Master Computer Science 2012 (optional subject), specialization field robotics and automation, 2nd or 3rd semester
- Master Computer Science 2012 (optional subject), advanced curriculum parallel and distributed system architecutres, 2nd or 3rd semester
- Master Computer Science 2012 (optional subject), advanced curriculum intelligent embedded systems, 2nd or 3rd semester
- Master Computer Science 2012 (compulsory), specialization field software systems engineering, 2nd semester

Classes and lectures:

- Hardware/Software Co-Design (lecture, 2 SWS)
- Hardware/Software Co-Design (exercise, 1 SWS)

Workload:

- 55 Hours private studies
- 45 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- System design flow
- Basic architectures for HW/SW systems
- System design and modelling
- System synthesis
- Algorithms for scheduling
- System partitioning
- Algorithms for system partitioning
- Design systems
- Performance analysis
- System design and specification with SystemC
- Application examples

Qualification-goals/Competencies:

- Students are able to determine a suitable hardware/software architecture for a given system description
- They are able to determine and describe the pros and cons of implementation alternatives
- They are able to apply methods for system partitioning
- They are able to translate non-formal system descriptions into formal models
- They are able to explain the different steps in system synthesis
- They are able to estimate the quality of system designs
- They are able to create system descriptions in SystemC

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr.-Ing. Mladen Berekovic

Teacher:

- Institute of Computer Engineering

- Prof. Dr.-Ing. Mladen Berekovic

Literature:

- F. Kesel: Modellierung von digitalen Systemen mit SystemC - Oldenbourg Verlag 2012
- Teich, J., Haubelt, C.: Digital Hardware/Software-Systeme. Synthese und Optimierung - Berlin: Springer 2007

Language:

- offered only in German

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercise assignments as specified at the beginning of the semester

Module Exam(s):
- CS5170-L1: Hardware/Software Co-Design, oral exam, 100% of the module grade

CS5204-KP04, CS5204 - Artificial Intelligence 2 (KI2)

Duration:	Turnus of offer:	Credit points:
1 Semester	each winter semester	4

Course of study, specific field and term:

- Master MES 2020 (optional subject), computer science / electrical engineering, Arbitrary semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 1st or 2nd semester
- Master Biophysics 2019 (optional subject), Elective, 1st semester
- Master MES 2014 (optional subject), computer science / electrical engineering, Arbitrary semester
- Master Biomedical Engineering (optional subject), Interdisciplinary modules, 2nd semester
- Master CLS 2016 (optional subject), computer science, 3rd semester
- Master Computer Science 2012 (optional subject), advanced curriculum intelligent embedded systems, 2nd or 3rd semester
- Master Computer Science 2012 (optional subject), specialization field robotics and automation, 3rd semester

Classes and lectures:

- Artificial Intelligence 2 (lecture, 2 SWS)
- Artificial Intelligence 2 (exercise, 1 SWS)

Workload:

- 55 Hours private studies
- 45 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Support Vector Machines and Dualization
- Classification
- Regression
- Time-Series Prediction
- Lagrange Multipliers
- Sequential Minimal Optimization
- Geometric Reasoning

Qualification-goals/Competencies:

- The students are able to choose a method for machine learning for a given application amongst a variety of such methods.
- The chosen method can be customized to the needs of the application. The process of customization goes well beyond straightforward search of parameters and involves adjustments to the basic mathematical techniques.This leads to innovative applications for machine learning, designed and implemented by the students.The starting point are support vector machines.

Grading through:

- Oral examination

Responsible for this module:

- Prof. Dr.-Ing. Achim Schweikard

Teacher:

- Institute for Robotics and Cognitive Systems

- Prof. Dr.-Ing. Achim Schweikard

Literature:

- P. Norvig, S. Russell: Künstliche Intelligenz - München: Pearson 2004

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- None

Module Exam(s):
- CS5204-L1: Artificial Intelligence 2, written exam, 90min, 100% of the module grade

CS5260-KP04, CS5260SJ14 - Speech and Audio Signal Processing (SprachAu14)

Duration:	**Turnus of offer:**	**Credit points:**
1 Semester	every second semester	4

Course of study, specific field and term:

- Master CLS 2023 (optional subject), Elective, Arbitrary semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, Arbitrary semester
- Master MES 2020 (optional subject), medical engineering science, Arbitrary semester
- Master Media Informatics 2020 (optional subject), computer science, Arbitrary semester
- Master Medical Informatics 2019 (optional subject), Medical Data Science / Artificial Intelligence, 1st or 2nd semester
- Master MES 2014 (optional subject), medical engineering science, Arbitrary semester
- Master CLS 2010 (optional suject), computer science, Arbitrary semester
- Master Medical Informatics 2014 (optional subject), computer science, 1st or 2nd semester
- Master Media Informatics 2014 (optional subject), computer science, Arbitrary semester

Classes and lectures:

- Speech and Audio Signal Processing (lecture, 2 SWS)
- Speech and Audio Signal Processing (exercise, 1 SWS)

Workload:

- 55 Hours private studies
- 45 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Speech production and human hearing
- Physical models of the auditory System
- Dynamic compression
- Spectral analysis: Spectrum and cepstrum
- Spectral perception and masking
- Vocal tract models
- Linear prediction
- Coding in time and frequency domains
- Speech synthesis
- Noise reduction and echo compensation
- Source localization and spatial reproduction
- Basics of automatic speech recognition

Qualification-goals/Competencies:

- Students are able to describe the basics of human speech production and the corresponding mathematical models.
- They are able to describe the process of human auditory perception and the corresponding signal processing tools for mimicing auditory perception.
- They are able to present basic knowledge of statistical speech modeling and automatic speech recognition.
- They can describe and use signal processing methods for source separation and room-acoustic measurements.

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr.-Ing. Markus Kallinger

Teacher:

- Institute for Signal Processing

- Prof. Dr.-Ing. Markus Kallinger

Literature:

- L. Rabiner, B.-H. Juang: Fundamentals of Speech Recognition - Upper Saddle River: Prentice Hall 1993
- J. O. Heller, J. L. Hansen, J. G. Proakis: Discrete-Time Processing of Speech Signals - IEEE Press

Language:

- offered only in German

Notes:

Prerequisites for attending the module:
- None

Prerequisites for the exam:
- Successful completion of assignments during the semester.

Modul exam:
- CS5260-L1: Speech and Audio Signal Processing, written or oral exam, 100% of modul grade

Mentioned in SGO MML under CS5260 (without SJ14).

RO4500-KP08 - Advanced Control and Estimation (ACE)

Duration:	Turnus of offer:	Credit points:
2 Semester	each semester	8

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 1st and 2nd semester

Classes and lectures:

- Linear Systems Theory (lecture, 2 SWS)
- Linear Systems Theory (exercise, 2 SWS)
- Graphical Models in Systems and Control (lecture, 2 SWS)
- Graphical Models in Systems and Control (exercise, 1 SWS)

Workload:

- 120 Hours in-classroom work
- 70 Hours private studies
- 30 Hours in-classroom exercises
- 20 Hours exam preparation

Contents of teaching:

- Content of teaching for course Linear Systems Theory:
- Vector spaces, norms, linear operators
- Eigenvalues, eigenvectors, Jordan normal form
- Singular value decomposition and operator norms
- Linear systems in continuous and discrete time
- Modeling of linear systems and linearization
- Fundamental solution to linear systems state equations
- Laplace transform and z-transform
- Content of teaching for course Graphical Models in Systems and Control:
- Introduction to Probability Theory, Discretely and Continuously Distributed Random Variables
- Fundamentals on Probabilistic Graphical Models
- Forney-Style Factor Graphs as a Probabilistic Graphical Model
- Message Passing via Sum- and Max-Produkt Algorithms
- Gaussian Message Passing
- State Estimation (Kalman Filtering and Smoothing including Nonlinear Extensions)
- Parameter Estimation via Expectation Maximization
- Expectation Propagation
- Control on Factor Graphs

Qualification-goals/Competencies:

- Educational objectives for course Linear Systems Theory:
- Students are familiar with the important basic concepts of linear algebra.
- Students have a solid background in the theory of linear systems in continuous and disrete time.
- Students are able to model linear systems in mechanical and electrical domain from first principles.
- Students are able to solve the state equations and analyze systems in the time and frequency domain.
- Students improve their problem solving and mathematical skills.
- Students develop their techniques for logical reasoning and and rigorous proofs.
- Students are enabled to perform reseaerch in the field of systems and control theory.
- Educational objectives for course Graphical Models in Systems and Control:
- Students develop and extend their fundamental knowledge on probability theory and the transformation of discretely as well as continuously distributed random variables.
- Students can understand simple linear algorithms, such as the Kalman filter, with the help of graphical probabilistic models.
- Students can combine elements of probabilistic algorithms to novel ones with the help of graphical probabilistic models.
- Students can understand, extend and apply advanced algorithms in signal processing, parameter and state estimation as well as control to relevant problems with the help of graphical probabilistic models.

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr. Philipp Rostalski
- Prof. Dr. Georg Schildbach

Teacher:

- Institute for Electrical Engineering in Medicine

- Prof. Dr. Georg Schildbach
- Prof. Dr.-Ing. Christian Herzog

Literature:

- Loeliger, Hans-Andrea; Dauwels, Justin; Hu, Junli; Korl, Sascha; Ping, Li; Kschischang, Frank R.: The Factor Graph Approach to Model-Based Signal Processing - Proc. IEEE, Vol. 95, No. 6, 2007
- Loeliger, Hans-Andrea: An Introduction to factor graphs - IEEE Signal Process. Mag., Vol. 21, No. 1, 2004
- Hoffmann, Christian; Rostalski, Philipp: Current Publications from Research at the IME
- Miscellaneous: Current Publications from Research

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises as specified at the beginning of the semester.

Module Exam(s):
- RO4500-L1: Advanced Control and Estimation, An oral examination on the contents of both submodules, 40min, 100% of the module grade.

RO5100-KP08 - Medical Robotics (MedRob08)

Duration:	Turnus of offer:	Credit points:
1 Semester	every summer semester	8

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 2nd semester

Classes and lectures:

- Inverse Problems in Image Processing (lecture, 2 SWS)
- Inverse Problems in Image Processing (exercise, 1 SWS)
- Medical Robotics (lecture, 2 SWS)
- Medical Robotics (exercise, 1 SWS)

Workload:

- 125 Hours private studies
- 90 Hours in-classroom work
- 25 Hours exam preparation

Contents of teaching:

- Introduction to inverse and ill-posed problems on the basis of selected examples (including seismology, impedance tomography, heat conduction, computed tomography, acoustics)
- Concept of ill-posedness of the inverse problem (Hadamard)
- Singular value decomposition and generalized inverse
- Regularization methods (eg Tikhonov, Phillips, Ivanov)
- Deconvolution
- Image restoration (deblurring, defocusing)
- Statistical methods (Bayes, maximum likelihood)
- Computed Tomography, Magnetic Particle Imaging

Qualification-goals/Competencies:

- Students are able to explain the concept of ill-posedness of the inverse problem and distinguish given inverse problems regarding good or bad posedness.
- They are able to formulate inverse problems of mathematical imaging and solve (approximate) with suitable numerical methods.
- They can assess the condition of a problem and the stability of a method.
- They master different regularization methods and are able to apply them to practical problems.
- They know methods to determine a suitable regularization.
- They can use methods of image reconstruction and restoration on real measurement data.
- Students are able to explain the concepts of forward and inverse kinematics for the examples of 3-joint and 6-joint robots.
- They are able to apply methods of medical robot systems and to simple practical applications.
- Students are able to transfer methods of motion learning to simple practical problems.
- Students are able to modify templates for dynamic calculations in order to create the calculations for their own constructions.

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr.-Ing. Achim Schweikard

Teacher:

- Institute of Medical Engineering
- Institute for Robotics and Cognitive Systems

Literature:

- Kak and Slaney: Principles of Computerized Tomographic Imaging - SIAM Series 33, New York, 2001
- Natterer and Wübbeling: Mathematical Methods in Image Reconstruction - SIAM Monographs, New York 2001
- Bertero and Boccacci: Inverse Problems in Imaging - IoP Press, London, 2002
- Andreas Rieder: Keine Probleme mit inversen Problemen - Vieweg, Wiesbaden, 2003
- Buzug: Computed Tomography - Springer, Berlin, 2008
- J. -C. Latombe: Robot Motion Planning - Dordrecht: Kluwer 1990
- J.J. Craig: Introduction to Robotics - Pearson Prentice Hall 2002
- : Vorlesungsskript: Med. Robotics

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercise assignments as specified at the beginning of the semester

Module Exam(s):
- RO5100-L1: Medical Robotics, one oral examination on the contents of both submodules, 100% of the module grade

RO5200-KP08 - Bio-inspired Robotics (BRS)

Duration:	**Turnus of offer:**	**Credit points:**
2 Semester	each year, can be started in winter or summer semester	8

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, Arbitrary semester

Classes and lectures:

- Collective Robotics (lecture, 2 SWS)
- Collective Robotics (exercise, 1 SWS)
- Evolutionary Robotics (lecture, 2 SWS)
- Evolutionary Robotics (exercise, 1 SWS)

Workload:

- 130 Hours private studies
- 90 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Biological basics
- Self-organization, robustness, scalability, superlinear speedups
- Robot swarms by land, by sea, and by air
- Mathematical modeling of swarms and collective decision-making
- Evolutionary computation
- Artificial evolution of robot controllers and robot morphologies
- Optimization and learning in robot experiments

Qualification-goals/Competencies:

- Students get a comprehensive overview of biologically inspired.
- Students are able to assess chances and challenges of robust and scalable robot systems.
- Students are able to implement reactive control for swarm robots in simulation and on mobile robots.
- Students are able to implement evolutionary algorithms and artificial neural networks and are able to apply them to problems of mobile robots in.
- Students are able to name challenges of evolutionary robotics in applications and to discuss potential solutions.

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr.-Ing. Mladen Berekovic

Teacher:

- Institute of Computer Engineering

- Dr. rer. nat. Javad Ghofrani

Literature:

- Nolfi, S., Floreano, D.: The Biology, Intelligence, and Technology of Self-Organizing Machines - MIT Press, 2001
- Hamann, H.: Swarm Robotics: A Formal Approach - Springer 2018

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises of both sub-modules as specified at the beginning of the respective semester.

Module Exam(s):
- RO5200-L1: Bio-inspired Robotics, oral examination on the contents of both submodules, 100% of the module grade

RO5500-KP08 - Autonomous Vehicles (AV)		
Duration:	**Turnus of offer:**	**Credit points:**
2 Semester	each semester	08

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 1st and 2nd semester

Classes and lectures:

- Vehicle Dynamics and Control (lecture, 2 SWS)
- Vehicle Dynamics and Control (exercise, 2 SWS)
- Perception for Autonomous Vehicles (lecture, 2 SWS)
- Perception for Autonomous Vehicles (exercise, 2 SWS)

Workload:

- 140 Hours private studies
- 60 Hours in-classroom work
- 40 Hours exam preparation

Contents of teaching:

- Content of teaching of the course Vehicle Dynamics and Control:
- Review of control methods and rigid body dynamics
- Basic terminology of vehicle dynamics
- Vehicle dynamic models (lateral, longitudinal, vertical)
- Component models (engine, transmission, brake, steering)
- Tire modeling
- Stability analysis
- Handling performance
- Active safety systems
- Autonomous driving
- Content of teaching of the course Perception for Autonomous Driving:
- The architecture of autonomous-driving systems
- Tracking, detection, classification
- Models of stochastic signals
- Transform-based analysis of stochastic signals
- System theory
- Parameter estimation
- Linear optimal filters and adaptive filters
- Graphical models and dynamic Bayes networks
- Neural networks
- Hidden Markov Models, Kalman Filter, Particle Filter, etc.
- Applications in the domain of autonomous driving

Qualification-goals/Competencies:

- Educational objectives of the course Vehicle Dynamics and Control:
- Students master basic terminology and concepts of vehicle dynamics.
- Students obtain a comprehensive understanding of the dynamics of a vehicle.
- Students understand the main objectives of vehicle control.
- Students can derive basic vehicle dynamics models for control design.
- Students are able to apply concepts of basic and advanced control and estimation to practical problems.
- Students get an insight into the field of active safety systems, driver assistance, and autonomous driving.
- Students are able to perform independent design, research and development work in this field.
- Educational objectives of the course Perception for Autonomous Driving:
- Students get an overview on autonomous-driving systems.
- Students become thoroughly acquainted with the perception layer of the architecture of an autonomous-driving system.
- Students get a comprehensive introduction to stochastic signals.
- Students master tools for the analysis of stochastic signals.
- Students are able to make use of various models for stochastic signals.
- Students are able to design tracking algorithms.
- Students are able devise algorithmic solutions to decision problems, while making use of prior knowledge.

Grading through:

- Written or oral exam as announced by the examiner

Requires:

- Control Systems (RO4400-KP08)
- Technical Mechanics (RO1500-KP08)

Responsible for this module:

- Prof. Dr. Georg Schildbach

Teacher:

- Institute for Electrical Engineering in Medicine

- Prof. Dr. Georg Schildbach
- PD Dr.-Ing. habil. Alexandru Paul Condurache

Literature:

- Rajamani, R: Vehicle Dynamics and Control (2nd edition) - Springer, 2012, ISBN 978-1-4614-1432-2
- Mitschke, M; Wallentowitz, H.: Dynamik der Kraftfahrzeuge (5th edition) - Springer, 2014 (ISBN: 978-3-658-05067-2)
- Charles W. Therrien: Decision estimation and classification - J. Wiley and Sons, 1991.
- Simon Haykin: Adaptive Filter Theory - Prentice Hall, 1996
- Christopher M. Bishop: Pattern recognition and machine learning - Springer, 2006
- A. Mertins: Signaltheorie: Grundlagen der Signalbeschreibung, Filterbänke, Wavelets, Zeit-Frequenz-Analyse, Parameter- und Signalschätzung - Springer-Vieweg, 3. Auflage, 2013

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises as specified at the beginning of the semester.

Module Examination(s):
- RO5500-L1: Vehicle Dynamics and Control, written exam, 60min, 50% of module grade
- RO5500-L2: Perception for Autonomous Vehicles, written exam, 60min, 50% of the module grade

RO5800-KP04, RO5801-KP04 - Advanced Topics in Robotics (ATiR)

Duration:	Turnus of offer:	Credit points:
1 Semester	each summer semester	4

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 1st or 2nd semester

Classes and lectures:

- Advanced Topics in Robotics (lecture, 2 SWS)
- Advanced Topics in Robotics (exercise, 1 SWS)

Workload:

- 55 Hours private studies
- 45 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Dynamics and Control of Robots
- Motion Planning for Robots
- Augmented Reality
- Design of Robot Systems
- Intracorporal Robotics

Qualification-goals/Competencies:

- Students understand the connection to underlying mathematical methods, especially in dynamics, optimization, and sensor data processing and analysis of algorithms.
- Students have an extended overview of application areas for robotics.
- They are able to implement such methods and derive new applications based on such methods.

Grading through:

- written exam, oral exam and/or presentation as announced by the examiner

Requires:

- Robotics (CS2500-KP04, CS2500)

Responsible for this module:

- Prof. Dr.-Ing. Achim Schweikard

Teacher:

- Institute for Robotics and Cognitive Systems

- Prof. Dr.-Ing. Achim Schweikard

Literature:

- Achim Schweikard, Floris Ernst: Medical Robotics - Springer, 2015, Jocelyne Troccaz (ed.): Medical Robotics, Wiley, 2009

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None (the competencies of the modules listed under

RO5800-KP08 - Advanced Topics in Robotics (ATR)

Duration:	Turnus of offer:	Credit points:
2 Semester	each year, can be started in winter or summer semester	8

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (optional subject), Elective, 1st or 2nd semester

Classes and lectures:

- Advanced Topics in Robotics (lecture, 2 SWS)
- Advanced Topics in Robotics (exercise, 1 SWS)
- Rescue Robotics (lecture, 2 SWS)
- Rescue Robotics (exercise, 2 SWS)

Workload:

- 105 Hours in-classroom work
- 95 Hours private studies
- 40 Hours exam preparation

Contents of teaching:

- Content of teaching of the course Advanced Topics in Robotics:
- Motion Planning for Robots
- Augmented Reality
- Design of Robot Systems
- Intracorporal Robotics
- Dynamics and Control of Robots
- Content of teaching of the course Rescue Robotics:
- Special requirements for disaster management and response and the resulting consequences on rescue robot design.
- Information structures for rescue systems
- Information exchange between rescue robots
- Command and control systems for search and rescue robots
- Tactical communication for cooperative SAR robot missions as well as interoperability in heterogeneous teams.
- Design guidelines for human interfaces to rescue robots
- Casualty and vital sign detection in rescue scenarios
- Medical assistance at the scene of incident and determination of vital signs
- Evaluation and benchmarking of SAR robots

Qualification-goals/Competencies:

- Educational objectives of the course Advanced Topics in Robotics:
- Students understand the connection to underlying mathematical methods, especially in dynamics, optimization, and sensor data processing and analysis of algorithms.
- Students have an extended overview of application areas for robotics.
- They are able to implement such methods and derive new applications based on such methods.
- Educational objectives of the course Rescue Robotics:
- The students can apply the tools to program and simulate mobile rescue robots. They have developed a good overview about mobile robotics, localization and path planning in difficult scenarios.
- The students have knowledge about the work and command structures of rescue personell and the requirements on control, communcation and interaction of rescue robots with the personnel.
- The students have developed a notion of medical first response by rescue personnel as well as technical solutions to locate missing persons, determine vital signs and realize medical assistance at the scene of incident.

Grading through:

- written exam, oral exam and/or presentation as announced by the examiner

Requires:

- Robotics (CS2500-KP04, CS2500)

Responsible for this module:

- Prof. Dr.-Ing. Achim Schweikard

Teacher:

- Institute for Robotics and Cognitive Systems
- Prof. Dr.-Ing. Achim Schweikard

- Prof. Dr. rer. nat. Floris Ernst

Literature:

- Achim Schweikard, Floris Ernst: Medical Robotics - Springer, 2015, Jocelyne Troccaz (ed.): Medical Robotics, Wiley, 2009
- Tadokoro, Satoshi, ed.: Rescue robotics: DDT project on robots and systems for urban search and rescue. - Springer Science & Business Media, 2009. (ISBN: 978-1447157656).
- Siciliano, Bruno, and Oussama Khatib, eds.: Springer handbook of robotics. - Springer, 2016. (ISBN: 978-3319325507)

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Entry requirements for taking module examination(s):
- RO5800: Advanced Topics in Robotics - None
- RO5803: Rescue Robotics - Successful completion of exercises as specified at the beginning of the semester.

Module Exam(s):
- RO5800-L1: Advanced Topics in Robotics, An oral examination covering the content of both sub-modules, 100% of module grade.

PS5000-KP06, PS5000 - Student Conference (ST)

Duration:	Turnus of offer:	Credit points:
1 Semester	each winter semester	6 (Typ B)

Course of study, specific field and term:

- Master Psychology - Cognitive Systems 2022 (compulsory), psychology, 3rd semester
- Master Biophysics 2023 (compulsory), biophysics, 3rd semester
- Master Auditory Technology 2022 (compulsory), Auditory Technology, 3rd semester
- Master MES 2020 (compulsory), interdisciplinary competence, 3rd semester
- Master Medical Informatics 2019 (compulsory), interdisciplinary competence, 3rd semester
- Master Biophysics 2019 (compulsory), biophysics, 3rd semester
- Master Auditory Technology 2017 (compulsory), Auditory Technology, 3rd semester
- Master Interdisciplinary Courses (optional subject), Interdisciplinary modules, Arbitrary semester
- Master Robotics and Autonomous Systems 2019 (compulsory), Compulsory courses, 3rd semester
- Master Medical Informatics 2014 (compulsory), interdisciplinary competence, 3rd semester
- Master MES 2014 (compulsory), interdisciplinary competence, 3rd semester

Classes and lectures:

- Student Conference (seminar, 4 SWS)

Workload:

- 155 Hours work on an individual topic (research and development) and written elaboration
- 25 Hours in-classroom work

Contents of teaching:

- Preparation of a scientific publication in English based on the results of at least one of the project internships
- Preparation of a scientific poster in English based on the results of at least one of the project internships
- Presentation of a scientific poster in German or English, based on the results of at least one of the project internships
- Talk in English based on the results of at least one of the project internships
- Active participation in scientific discussions
- Active participation in a scientific peer-review process

Qualification-goals/Competencies:

- Students have experience in a comprehensive review of a scientific topic
- They are able to get an extensive overview of a complex scientific area
- They have the experience and ability to take an active part in scientific discussions
- They are able to defend one's work successfully in a scientific discourse
- They have knowledge of the peer-review process of publications
- They are able to constructively criticize in a blind peer-review process
-

Grading through:

- continuous, successful participation in course

Responsible for this module:

- Prof. Dr. rer. nat. habil. Heinz Handels
- Prof. Dr. rer. nat. Thorsten Buzug

Teacher:

- All Institutes and Clinics of the Universität zu Lübeck

Literature:

- is selected individually:

Language:

- offered only in English

Notes:

Admission requirements for the module:
- Successful completion of at least one project internship.
- Registration for at least one project internship is required.

Admission requirements for the examination:
- Regular and successful participation

Since the content of the presentation should reflect the results of at least one of the project internships, the students will be supervised by the same university lecturer that supervised the internships. Internships can be carried out at home or abroad in medical technology companies, audiology companies and IT companies in the healthcare industry as well as hospitals and scientific institutions. The supervision by an university lecturer is obligatory.

Students for whom this course is a compulsory module have priority.

(The share of the Institute of Medical Technology in all is 75%)
(Share of medical informatics in all is 25%)

RO4000-KP12 - Autonomous Systems (AS)

Duration:	Turnus of offer:	Credit points:
2 Semester	each winter semester	12

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (compulsory), Compulsory courses, 1st and 2nd semester

Classes and lectures:

- Real-Time Systems (lecture, 2 SWS)
- Real-Time Systems (exercise, 2 SWS)
- Model Predictive Control (lecture, 2 SWS)
- Model Predictive Control (exercise, 2 SWS)

Workload:

- 140 Hours private studies
- 120 Hours in-classroom work
- 40 Hours exam preparation

Contents of teaching:

- Content of teaching of the course Real-Time Systems:
- Real-time processing (definitions, requirements)
- Process automation systems
- Real-time programming
- Process connectivity and networking
- Modelling of discrete event systems (automata, state charts)
- Modelling of continuous systems (differential equations, Laplace transformation)
- Application of design tools (Matlab/Simulink, Stateflow)
- Content of teaching of the course Model Predictive Control:
- LQ optimal control and Kalman filter
- Convex optimization
- Invariant sets
- Theory of Model Predictive Control (MPC)
- Algorithms for numerical optimization
- Explicit MPC
- Practical aspects (Robust MPC, Offset-free tracking, etc.)
- MPC applications

Qualification-goals/Competencies:

- Educational objectives of the course Real-Time Systems:
- The students are able to describe the fundamental problems of real-time processing.
- They are able to explain real-time computer systems for process automation, in particular SPS.
- They are able to program real-time systems in the IEC languages.
- They are able to elucidate process interfaces and real-time bus system.
- They are able to model, analyze and implement event discrete systems, in particular process control systems.
- They are able to model, analyze and implement continuous systems, in particular feedback control systems.
- They are able to make use of design tools for real-time systems.
- Educational objectives of the course Model Predictive Control:
- Students get a comprehensive introduction to methods of optimal control.
- Students get an overview of the fundamentals of numerical optimization.
- Students are able to design model predictive controllers for linear and nonlinear systems.
- Students get acquainted with several tools to implement model predictive controllers.
- Students are able to establish system theoretic properties of model predictive controllers.
- Students gain insight into possible applications areas for MPC.

Grading through:

- Written or oral exam as announced by the examiner

Requires:

- Control Systems (RO4400-KP08)

Responsible for this module:

- Prof. Dr. Georg Schildbach

- Prof. Dr.-Ing. Mladen Berekovic

Teacher:

- Institute for Electrical Engineering in Medicine
- Institute of Computer Engineering

- Prof. Dr.-Ing. Mladen Berekovic
- MitarbeiterInnen des Instituts
- Prof. Dr. Georg Schildbach
- MitarbeiterInnen des Instituts

Literature:

- R. C. Dorf, R. H. Bishop: Modern Control Systems - Prentice Hall 2010
- L. Litz: Grundlagen der Automatisierungstechnik - Oldenbourg 2012
- M. Seitz: Speicherprogrammierbare Steuerungen - Fachbuchverlag Leipzig 2012
- H. Wörn, U. Brinkschulte: Echtzeitsysteme - Berlin: Springer 2005
- S. Zacher, M. Reuter: Regelungstechnik für Ingenieure - Springer-Vieweg 2014
- F. Borrelli, A. Bemporad, M. Morari: Predictive Control for Linear and Hybrid Systems - Cambridge University Press, 2017 (ISBN: 978-1107016880)

Language:

- German and English skills required

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises as specified at the beginning of the semester.

Module Exam(s):
- RO4000-L1: Autonomous Systems, participation in the written examinations of both submodules.
- RO4001-L1: Model Predictive Control, written exam, 90 min, 50% of the module grade
- CS4160-L1: Real-Time Systems, written exam, 90min, 50% of module grade

RO4100-KP08 - Robot Learning (RobLe)

Duration:	Turnus of offer:	Credit points:
2 Semester	each year, can be started in winter or summer semester	8

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (compulsory), Compulsory courses, 1st and 2nd semester

Classes and lectures:

- CS4575-V: Sequence Learning (lecture, 2 SWS)
- CS4575-Ü: Sequence Learning (exercise, 1 SWS)
- CS4295-V: Deep Learning (lecture, 2 SWS)
- CS4295-Ü: Deep Learning (exercise, 1 SWS)

Workload:

- 120 Hours work on project
- 120 Hours private studies
- 60 Hours in-classroom exercises
- 60 Hours in-classroom work

Contents of teaching:

- Foundations and Deep Learning Basics (Learning Paradigms, Classification and Regression, Underfitting and Overfitting)
- Shallow Neural Networks (Basic Neuron Model, Multilayer Perceptions, Backpropagation, Computational Graphs, Universal Approximation Theorem, No-Free Lunch Theorems, Inductive Biases)
- Optimization (Stochastic Gradient Descent, Momentum Variants, Adaptive Optimizer)
- Convolutional Neural Networks (1D Convolution, 2D Convolution, 3D Convolution, ReLUs and Variants, Down and Up Sampling Techniques, Transposed Convolution)
- Regularization (Early Stopping, L1 and L2 Regularization, Label Smoothing, Dropout Strategies, Batch Normalization)
- Very Deep Networks (Highway Networks, Residual Blocks, ResNet Variants, DenseNets)
- Dimensionality Reduction (PCA, t-SNE, UMAP, Autoencoder)
- Generative Neural Networks (Variational Autoencoder, Generative Adversarial Networks, Diffusion Models)
- Graph Neural Networks (Graph Convolutional Networks, Graph Attention Networks)
- Fooling Deep Neural Networks (Adversarial Attacks, White Box and Black Box Attacks, One-Pixel Attacks)
- Physics-Aware Deep Learning (Physical Knowledge as Inductive Bias, PINN, PhyDNet, Neural ODE, FINN)
- Introduction to Sequence Learning (Formalisms, Metrics, Recapitulation of Relevant Machine Learning Techniques)
- Recurrent Neural Networks (Simple RNN Models, Backpropagation Through Time)
- Gated Recurrent Networks (Vanishing Gradient Problem in RNNs, Long Short-Term Memories, Gated Recurrent Units, Stacked RNNs)
- Important Techniques for RNNs (Teacher Forcing, Scheduled Sampling, h-Detach)
- Bidirectional RNNs and related concepts
- Hierarchical RNNs and Learning on Multiple Time Scales
- Online Learning and Learning without BPTT (Real-Time Recurrent Learning, e-Prop, Forward Propagation Through Time)
- Reservoir Computing (Echo State Networks, Deep ESNs)
- Spiking Neural Networks (Spiking Neuron Models, Learning in SNNs, Neuromorphic Computing, Recurrent SNNs)
- Temporal Convolution Networks (Causal Convolution, Temporal Dilation, TCN-ResNets)
- Introduction to Transformers (Sequence-to-Sequence Learning, Basics on Attention, Self-Attention and the Query-Key-Value Principle, Large Language Models)
- State Space Models (Structured State Space Sequence Models, Mamba)

Qualification-goals/Competencies:

- Students get a fundamental understanding deep learning basics such as backpropagation, computational graphs, and auto-differentiation
- Students understand the implications of inductive biases
- Students get a comprehensive understanding of most relevant deep learning approaches
- Students learn to analyze the challenges in deep learning tasks and to identify well-suited approaches to solve them
- Students will understand the pros and cons of various deep learning models
- Students know how to analyze the models and results, to improve the model parameters, and to interpret the model predictions and their relevance
- Students get a comprehensive understanding of most relevant sequence learning approaches
- Students learn to analyze the challenges in sequence learning tasks and to identify well-suited approaches to solve them
- Students will understand the pros and cons of various sequence learning models
- Students can implement common and custom sequence learning models for time series analysis, classification, and forecasting
- Students know how to analyze the models and results, to improve the model parameters, and to interpret the model predictions and their relevance

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr. Sebastian Otte

Teacher:

- Institute for Robotics and Cognitive Systems

- MitarbeiterInnen des Instituts
- Prof. Dr. Sebastian Otte

Literature:

- Goodfellow, I., Bengio, Y., & Courville, A.: Deep Learning - MIT Press (2016), ISBN 978-0262035613
- Nakajima, K., & Fischer, I.: Reservoir Computing: Theory, Physical Implementations, and Applications - Springer Nature Singapore (2021), ISBN 978-9811316869
- Sun, R., & Giles, C.: Sequence Learning: Paradigms, Algorithms, and Applications - Springer Berlin Heidelberg (2001), ISBN 978-3540415978
- Bishop, C. M.: Pattern Recognition and Machine Learning - Springer (2006), ISBN 978-0387310732
- Sutton, R., & Barto, A.: Reinforcement Learning: An Introduction - The MIT Press (2018), ISBN 978-0262039246
- François-Lavet, V., Henderson, P., Islam, R., Bellemare, M., & Pineau, J.: An Introduction to Deep Reinforcement Learning - Now Publishers Inc (2018), ISBN 978-1680835380
- Recent publications on the related topics:

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercise assignments as specified at the beginning of the semester

Module Exam(s):
- CS4295-L1: Deep Learning, exam, 90 min, 50% of the module grade
- CS4575-L1: Sequence Learning, exam, 90 min, 50% of the module grade

RO4300-KP08 - Machine Learning and Computer Vision (MLRAS)

Duration:	Turnus of offer:	Credit points:
2 Semester	normally each year in the winter semester	8

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (compulsory), Compulsory courses, 1st and 2nd semester

Classes and lectures:

- Machine Learning (lecture, 2 SWS)
- Machine Learning (exercise, 1 SWS)
- Computer Vision (lecture, 2 SWS)
- Computer Vision (exercise, 1 SWS)

Workload:

- 110 Hours private studies
- 90 Hours in-classroom work
- 40 Hours exam preparation

Contents of teaching:

-
- Representation learning, including manifold learning
- Statistical learning theory
- VC dimension and support vector machines
- Boosting
- Deep Learning
- Limits of induction and importance of data ponderation
-
- Introduction to human and computer vision
- Sensors, cameras, optics and projections
- Image features: edges, intrinsic dimension, Hough transform, Fourier descriptors, snakes
- Range imaging and 3-D cameras
- Motion and optical flow
- Object recognition
- Example applications

Qualification-goals/Competencies:

-
- Students can understand and explain various machine-learning problems.
- They can explain and apply different machine learning methods and algorithms.
- They can chose and then evaluate an appropriate method for a particular learning problem.
- They can understand and explain the limits of automatic data analysis.
-
- Students can understand the basics of computer vision.
- They can explain and perform camera choice and calibration.
- They can explain and apply the basic methods for feature extraction, motion estimation, and object recognition.
- They can indicate appropriate methods for different kinds of computer-vision applications.

Grading through:

- Oral examination

Responsible for this module:

- Prof. Dr.-Ing. Erhardt Barth

Teacher:

- Institute for Neuro- and Bioinformatics

- Prof. Dr.-Ing. Erhardt Barth
- Prof. Dr. rer. nat. Thomas Martinetz

Literature:

- Chris Bishop: Pattern Recognition and Machine Learning - Springer ISBN 0-387-31073-8
- Vladimir Vapnik: Statistical Learning Theory - Wiley-Interscience, ISBN 0471030031
- Richard Szeliski: Computer Vision: Algorithms and Applications - Springer, Boston, 2011

- David Forsyth and Jean Ponce: Computer Vision: A Modern Approach - Prentice Hall, 2003

Language:

- English, except in case of only German-speaking participants

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises of both sub-modules as specified at the beginning of the respective semester.

Module Exam(s):
- RO4300-L1: Machine Learning and Computer Vision, oral examination on the contents of both submodules, 100% of the module grade

RO5000-KP12 - Internship Robotics and Autonomous Systems 1 (ProPraRAS1)

Duration:	Turnus of offer:	Credit points:
1 Semester	each winter semester	12

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (compulsory), Compulsory courses, 3rd semester

Classes and lectures:

- Internship 1 (block practical course, 12 SWS)

Workload:

- 320 Hours work on project
- 40 Hours written report

Contents of teaching:

- project task in a specific application scenario
- documentation, presentation, motivation in a heterogeneous environment
- the project task is embedded in a heterogeneous and vivid environment with substantial communication and integration demands

Qualification-goals/Competencies:

- The students have a deep understanding of selected aspects of robotics and autonomous systems.
- They are able to implement selected aspects of robotics and autonomous systems.
- They are able to document and present project results.
- They are capacble of presenting to particular audiences or under time restrictions (eg elevator pitch etc.).
- They have project experience in concrete application scenarios.
- They have basic skills in the field of project management.

Grading through:

- documentation

Responsible for this module:

- Prof. Dr. Philipp Rostalski

Teacher:

- Institute of Computer Engineering
- Institute for Robotics and Cognitive Systems
- Institute for Electrical Engineering in Medicine

Language:

- English, except in case of only German-speaking participants

Notes:

Admission requirements for taking the module:
- Registration of the internships with the chair of the examination board is mandatory for later recognition. The corresponding forms can be found in the download area of the study program homepage.

Admission requirements for taking module examination(s):
- Regular and successful participation in the internship

Module Exam(s):
- RO5000-L1: Internship Robotics and Autonomous Systems 1, block practical with final report, 100% of module grade.

The internships can be completed at the University of Lübeck as well as at external universities, research institutions and companies in the field of robotics and autonomous systems in Germany and abroad.

Both project internships can be combined into one large internship.

(Proportion of LE Computer Science/Engineering in BP is 100%).

RO5001-KP12 - Internship Robotics and Autonomous Systems 2 (ProPraRAS2)		
Duration:	**Turnus of offer:**	**Credit points:**
1 Semester	each winter semester	12

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (compulsory), Compulsory courses, 3rd semester

Classes and lectures:

- Internship 2 (block practical course, 12 SWS)

Workload:

- 320 Hours work on project
- 40 Hours written report

Contents of teaching:

- project task in a specific application scenario
- documentation, presentation, motivation in a heterogeneous environment
- the project task is embedded in a heterogeneous and vivid environment with substantial communication and integration demands

Qualification-goals/Competencies:

- The students have a deep understanding of selected aspects of medical engineering.
- They are able to implement selected aspects of robotics and autonomous systems.
- They are able to document and present project results.
- They are capacble of presenting to particular audiences or under time restrictions (eg elevator pitch etc.).
- They have project experience in concrete application scenarios.
- They have basic skills in the field of project management.

Grading through:

- documentation

Responsible for this module:

- Prof. Dr. Philipp Rostalski

Teacher:

- Institute of Computer Engineering
- Institute for Robotics and Cognitive Systems
- Institute for Electrical Engineering in Medicine

- Alle prüfungsberechtigten Dozentinnen/Dozenten des Studienganges

Language:

- English, except in case of only German-speaking participants

Notes:

Admission requirements for taking the module:
- Registration of the internships with the chair of the examination board is mandatory for later recognition. The corresponding forms can be found in the download area of the study program homepage.

Admission requirements for taking module examination(s):
- Regular and successful participation in the internship

Module Exam(s):
- RO5001-L1: Internship Robotics and Autonomous Systems 2, block practical with final report, 100% of module grade.

The internships can be completed at the University of Lübeck as well as at external universities, research institutions and companies in the field of robotics and autonomous systems in Germany and abroad.

Both project internships can be combined into one large internship.

(Proportion of LE Computer Science/Engineering in BP is 100%).

RO5990-KP30 - Master Thesis Robotics and Autonomous Systems (MScRAS)

Duration:	Turnus of offer:	Credit points:
1 Semester	each semester	30

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (compulsory), Compulsory courses, 4th semester

Classes and lectures:

- Master's Thesis (supervised self studies, 1 SWS)
- Colloquium (presentation (incl. preparation), 1 SWS)

Workload:

- 870 Hours research for and write up of a thesis
- 30 Hours oral presentation and discussion (including preparation)

Contents of teaching:

- individual studies under supervision

Qualification-goals/Competencies:

- Students are able to solve a complex scientific problem by the means of their discipline.
- They have the expertise to plan, organize and carry out a project work.
- They can present complex information in written and oral form.
- They are experts for a roughly defined topic.

Grading through:

- Written report

Responsible for this module:

- Studiengangsleitung Robotik und Autonome Systeme

Teacher:

- Institutes of the Department of Computer Science/ Engineering

- Alle prüfungsberechtigten Dozentinnen/Dozenten des Studienganges

Literature:

- links will be given by the supervisor:

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- See study program regulations (e.g. certain minimum CP achieved).

Admission requirements for participation in module examination(s):
- see study program regulations

Module Exam(s):
- RO5990-L1: Masterarbeit Robotics and Autonomous Systems, final paper, 100% of module grade.

CS4660-KP04, CS4660 - Process Control Systems (ProzFueSys)

Duration:	Turnus of offer:	Credit points:
1 Semester	each winter semester	4

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (optional subject), Module part Current Issues Robotics and Automation, Arbitrary semester
- Master Psychology 2016 (optional subject), interdisciplinary competence, 3rd semester
- Master psychology 2013 (optional subject), interdisciplinary competence, 3rd semester
- Master Media Informatics 2014 (compulsory), computer science, 3rd semester
- Master Computer Science 2012 (optional subject), specialization field robotics and automation, 2nd or 3rd semester
- Master Computer Science 2012 (compulsory), specialization field media informatics, 2nd semester

Classes and lectures:

- Process Control Systems (lecture, 2 SWS)
- Process Control Systems (exercise, 1 SWS)

Workload:

- 55 Hours private studies
- 45 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Introduction and Overview
- Incidents and Accidents
- Error, Failure and Responsibility
- Human Factors
- Mental, conceptual and technical Models
- Task Analysis and Task Modelling
- Event Analysis and Event Modelling
- Task Allocation
- Situation Awareness
- Diagnoses und Contingency
- Interaction in real-time: Conception and Design
- Risk and Safety
- Operations and Safety

Qualification-goals/Competencies:

- The students know the most important theories, methods and systems for monitoring and controlling processes.
- They know the definitions of the terms risk and security and why they are applied in different ways.
- They can assess what needs to be considered in the development of mission- and safety-critical human-machine systems and how to proceed methodically.

Grading through:

- written exam

Responsible for this module:

- Prof. Dr. phil. André Calero Valdez

Teacher:

- Institute for Multimedia and Interactive Systems

- Prof. Dr. phil. André Calero Valdez

Literature:

- M. Herczeg: Prozessführungssysteme Sicherheitskritische Mensch-Maschine-Systeme und Interaktive Medien zur Überwachung und Steuerung von Prozessen in Echtzeit - München: de Gruyter - Oldenbourg-Verlag, 2014
- M. Herczeg: Software-Ergonomie: Theorien, Modelle und Kriterien für gebrauchstaugliche interaktive Computersysteme - 4. erweiterte und aktualisierte Auflage. De Gruyter Studium, 2018
- M. Herczeg: Interaktionsdesign - München: Oldenbourg-Verlag, 2006
- J. Reason: Human Error - Boston: Cambridge University Press, 1990
- J. Rasmussen, L. P. Goodstein, A. M. Peijtersen: Cognitive Systems Engineering - New York: Wiley, 1994

Language:

- offered only in German

Notes:

Prerequisites for attending the module:
- None

Prerequisites for the exam:
- Successful completion of homework assignments during the semester.

CS5275 T - Module part: Selected Topics of Signal Analysis and Enhancement (AMSAVa)

Duration:	Turnus of offer:	Credit points:
1 Semester	each summer semester	4

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (module part), Module part Current Issues Robotics and Automation, 1st and/or 2nd semester
- Master Biophysics 2023 (module part), advanced curriculum, 2nd semester
- Master Computer Science 2019 (module part), Module part, Arbitrary semester
- Master MES 2020 (module part), computer science / electrical engineering, Arbitrary semester
- Master Entrepreneurship in Digital Technologies 2020 (module part), Module part, Arbitrary semester
- Master Biophysics 2019 (module part), advanced curriculum, 2nd semester
- Master IT-Security 2019 (module part), Module part, 1st or 2nd semester
- Master Entrepreneurship in Digital Technologies 2014 (module part), Module part, Arbitrary semester
- Master MES 2014 (module part), computer science / electrical engineering, 1st or 2nd semester
- Master Computer Science 2014 (module part), Module part, Arbitrary semester

Classes and lectures:

- Selected Topics of Signal Analysis and Enhancement (lecture, 2 SWS)
- Selected Topics of Signal Analysis and Enhancement (exercise, 1 SWS)

Workload:

- 55 Hours private studies
- 45 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Introduction to statistical signal analysis
- Autocorrelation and spectral estimation
- Linear estimators
- Linear optimal filters
- Adaptive filters
- Multichannel signal processing, beamforming, and source separation
- Compressed sensing
- Basic concepts of multirate signal processing
- Nonlinear signal processing algorithms
- Application scenarios in auditory technology, enhancement, and restauration of one- and higher-dimensional signals, Sound-field measurement, noise reduction, deconvolution (listening-room compensation), inpainting

Qualification-goals/Competencies:

- Students are able to explain the basic elements of stochastic signal processing and optimum filtering.
- They are able to describe and apply linear estimation theory.
- Students are able to describe the concepts of adaptive signal processing.
- They are able to describe and apply the concepts of multichannel signal processing.
- They are able to describe the concept of compressed sensing.
- They are able to analyze and design multirate systems.
- Students are able to explain various applications of nonlinear and adaptive signal processing.
- They are able to create and implement linear optimum filters and nonlinear signal enhancement techniques on their own.

Grading through:

- exam type depends on main module

Responsible for this module:

- Siehe Hauptmodul

Teacher:

- Institute for Signal Processing

- Prof. Dr.-Ing. Markus Kallinger

Literature:

- A. Mertins: Signaltheorie: Grundlagen der Signalbeschreibung, Filterbänke, Wavelets, Zeit-Frequenz-Analyse, Parameter- und

Signalschätzung - Springer-Vieweg, 3. Auflage, 2013
- S. Haykin: Adaptive Filter Theory - Prentice Hall, 1995

Language:

- offered only in German

Notes:

(Part of modules CS4290, CS4510, CS5400, RO4290-KP04, CS5274-KP08)
(Is equal to CS5275)

For Details see main module.

Prerequisites for attending the module:
- None

Prerequisites for the exam:
- Successful completion of homework assignments during the semester (at least 50%).

Modul exam in Main module:
- CS5275-L1: Selected Topics of Signal Analysis and Enhancement, written or oral exam, 100% of modul grade

CS5280 T - Module Part: Seminar Robotics and Automation (SemRobAuta)

Duration:	Turnus of offer:	Credit points:
1 Semester	each semester	4

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (optional subject), Module part Current Issues Robotics and Automation, Arbitrary semester
- Master Computer Science 2014 (Module part of a compulsory module), specialization field robotics and automation, Arbitrary semester

Classes and lectures:

- Advanced Seminar Robotics and Automation (seminar, 2 SWS)

Workload:

- 90 Hours work on an individual topic with written and oral presentation
- 30 Hours in-classroom work

Contents of teaching:

- Different topics from the fields of robotics and artificial intelligence for term papers are offered.
- The students learn the correct reading of scientific papers, research and investigation, correct quotation and structuring, and self-contained writing and presentation of their own scientific elaboration as a preparation for their final examination.

Qualification-goals/Competencies:

- The participants are able to do research on scientific publications, to analyze the contents and to understand them.
- The students are able to investigate self-dependently scientific publications, to analyze and understand their contents.
- The participants can analyze and reproduce the tenor with regard to their scope of work. The students are competent to write and present their own scientific work.

Grading through:

- exam type depends on main module

Responsible for this module:

- Siehe Hauptmodul

Teacher:

- Institute for Electrical Engineering in Medicine
- Institute for Robotics and Cognitive Systems
- Institute of Computer Engineering

- Prof. Dr.-Ing. Mladen Berekovic
- Prof. Dr.-Ing. Achim Schweikard
- Prof. Dr. Philipp Rostalski

Language:

- English, except in case of only German-speaking participants

Notes:

Prerequisites for attending the module:
- None

RO4210-KP04 - Path Planning and Control of Wheeled Robots (PPaCWR)		
Duration:	**Turnus of offer:**	**Credit points:**
1 Semester	each winter semester	4

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (module part), Module part Current Issues Robotics and Automation, Arbitrary semester

Classes and lectures:

- RO4200-V: Path Planning and Control of Wheeled Robots (lecture, 2 SWS)
- RO4200-Ü: Path Planning and Control of Wheeled Robots (exercise, 1 SWS)

Workload:

- 75 Hours private studies
- 45 Hours in-classroom work

Contents of teaching:

- Students are familiarwith kinematic and dynamic modeling of wheeled mobile robots
- Students are familiar with path planning methods for wheeled robots and important issues
- Students are familiar with trajectory tracking control of wheeled mobile robots
- Students are able to implement the methods mentioned above using Matlab

Qualification-goals/Competencies:

- Classification of wheeled mobile robots
- Types of wheels and wheel configurations
- Difference between mobile robots and robot arms
- Kinematic nonholonomic constraints on wheels
- Degrees of mobility, steerability, and maneuverability
- Forward kinematics (unicycle, differential-drive robot, car-like robot, n-trailer systems)
- Inverse kinematics
- Lagrange dynamic approach
- Newton-Euler approach
- Path planning vs trajectory planning
- Trajectory planning
- Path planning using artificial potential fields
- Planning via retraction
- Planning via cell decomposition
- Probabilistic planning
- Application of MPC Controller on wheeled robots
- Trajectory tracking
- Leader-Follower trajectory tracking control
- Control of multi-robot systems

Grading through:

- portfolio exam

Responsible for this module:

- Prof. Dr. Georg Schildbach

Teacher:

- Institute for Electrical Engineering in Medicine

- Prof. Dr. Behnam Miripour Fard

Literature:

- M.W. Spong, S. Hutchinson, and M. Vidyasagar: Robot Modeling and Control - 2nd ed. John Wiley & Sons, 2020
- R. Siegwart, I.R. Nourbakhsh, D. Scaramuzza: Introduction to Autonomous Mobile Robots - MIT Press, 2011
- B. Siciliano, L. Sciavicco, L. Villani, G. Oriolo: Robotics - Modelling, Planning and Control - 3rd Edition, Springer, 2009
- H. Choset, K. Lynch, S. Hutchinson, G. Kantor, W. Burgard, L. Kavraki, and S. Thrun: Principles of Robot Motion - Theory, Algorithms, and Implementation - MIT Press, 2005

Language:

- offered only in English

Notes:

This module can only be taken as one module from the Current Issues Robotics and Automation (CS4290-KP04, CS4290) catalog.

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercise slips as specified at the beginning of the semester.

Module Exam(s):
RO4210-L1: Portfolio Examination Path Planning and Control of Wheeled Robots with a total of 100 points, divided as follows:
- 60 points for submission of homework
- 40 points for an e-test

CS3110-KP04, CS3110 - Computer-Aided Design of Digital Circuits (SchaltEntw)

Duration:	Turnus of offer:	Credit points:
1 Semester	each winter semester	4

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (optional subject), Additionally recognized elective module, Arbitrary semester
- Master MES 2020 (optional subject), computer science / electrical engineering, Arbitrary semester
- Bachelor Computer Science 2016 (optional subject), major subject informatics, Arbitrary semester
- Bachelor Robotics and Autonomous Systems 2016 (optional subject), computer science, 5th or 6th semester
- Bachelor IT-Security 2016 (optional subject), computer science, Arbitrary semester
- Bachelor MES 2014 (optional subject), computer science / electrical engineering, 5th or 6th semester
- Bachelor Computer Science 2014 (optional subject), central topics of computer science, 5th or 6th semester
- Bachelor MES 2011 (optional subject), Applied computer science, 3rd, 5th, or 6th semester
- Bachelor CLS 2010 (optional subject), computer science, 5th or 6th semester
- Bachelor Computer Science 2012 (optional subject), central topics of computer science, 5th or 6th semester

Classes and lectures:

- Computer-Aided Design of Digital Circuits (lecture, 2 SWS)
- Computer-Aided Design of Digital Circuits (exercise, 1 SWS)

Workload:

- 55 Hours private studies
- 45 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Abstraction levels in circuit design
- Design cycle and design strategies
- FPGA architectures
- Introduction of the hardware description language VHDL
- Design of standard components in VHDL
- Circuit design at different abstraction levels
- Circuit design for synthesis
- VHDL simulation cycle
- VHDL circuit design for FPGAs
- Designing Testbenches
- High-Level-Synthesis

Qualification-goals/Competencies:

- Based on a non-formal description of a digital system, students are able to design digital circuits using VHDL
- They are able to simulate and test VHDL descriptions
- They are able to explain the internal structures of FPGAs
- They are able to determine which VHDL construct will result in which circuit structure
- They are able to explain the VHDL simulation cycle
- They are able to write synthesizable VHDL code

Grading through:

- written exam

Requires:

- Fundamentals of Computer Engineering 2 (CS1202-KP06, CS1202)

Responsible for this module:

- Prof. Dr.-Ing. Mladen Berekovic

Teacher:

- Institute of Computer Engineering

- Prof. Dr.-Ing. Mladen Berekovic

Literature:

- F. Kesel, R. Bartholomä: Entwurf von digitalen Schaltungen und Systemen mit HDLs und FPGAs - Oldenbour Verlag 2009

- C.Maxfield: The Design Warrior's Guide to FPGAs - Newnes 2004

Language:

- offered only in German

Notes:

Admission requirements for taking the module:
- None (the competencies of the modules listed under

CS4452-KP06 - Reliability Engineering (TechZuv)

Duration:	Turnus of offer:	Credit points:
1 Semester	normally each year in the winter semester	6

Course of study, specific field and term:

- Master Computer Science 2019 (optional subject), Elective, Arbitrary semester
- Master IT-Security 2019 (optional subject), IT Safety and Reliability, 1st, 2nd, or 3rd semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Additionally recognized elective module, Arbitrary semester

Classes and lectures:

- Reliability Engineering (lecture, 2 SWS)
- Reliability Engineering (exercise, 2 SWS)

Workload:

- 100 Hours private studies
- 60 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Basic concepts
- Reliability analysis
- Qualification tests
- Maintainability analysis
- Design guidelines for reliability, maintainability and software quality

Qualification-goals/Competencies:

- Students are able to discuss the basic concepts of Reliabilty Engineering
- They are able to analyze the reliability of technical systems by mathematical models
- They are able to select and apply qualification tests
- They are able to perform a maintainability analysis
- They are able to follow design guidelines for reliable and maintainable systems.

Grading through:

- Viva Voce or test

Responsible for this module:

- Prof. Dr.-Ing. Mladen Berekovic

Teacher:

- Institute of Computer Engineering
- Prof. Dr.-Ing. Mladen Berekovic

Literature:

- A. Birolini: Reliability Engineering: Theory and Practice - Springer 2013
- M. Rausand: Reliability of Safety-Critical Systems - Wiley 2014

Language:

- English, except in case of only German-speaking participants

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises as specified at the beginning of the semester.

Module Exam(s):
- CS4452-L1: Technical Reliability, written exam, 90min, 100% of the module grade.

According to the decision of the examination board of computer science of 15.1.2020 this module can be chosen by students Master Computer Science SGO from 2019 in the area of 5th elective.

CS4480-KP04 - System Identification (Sysiden)

Duration:	Turnus of offer:	Credit points:
1 Semester	irregularly in the summer semester	4

Course of study, specific field and term:

- Master MES 2020 (optional subject), computer science / electrical engineering, Arbitrary semester
- Master MES 2014 (optional subject), computer science / electrical engineering, Arbitrary semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Additionally recognized elective module, 1st or 2nd semester

Classes and lectures:

- System Identification (lecture, 2 SWS)
- System Identification (exercise, 1 SWS)

Workload:

- 65 Hours private studies and exercises
- 45 Hours in-classroom work
- 10 Hours exam preparation

Contents of teaching:

- Introductory topics:
- Discretization and Discrete-time (DT) models
- Least-square estimation
- Main topics:
- Parametric model identification: Prediction error method, Subspace identification
- Non-parametric model identification
- Data-driven models
- Model Validation

Qualification-goals/Competencies:

- The students can explain the general framework and basic properties of different identification methods including least-squares method, the prediction error method, the subspace method, standard non-parametric methods and the data-driven method.
- Students can formulate and implement algorithms for system identification.
- students are able to estimate mathematical models of a dynamical system from input-output data using the different methods presented in this course.
- They can evaluate the quality of the identified models.
- They can use Matlab System Identification Toolbox to identify linear dynamical models using different identification methods.

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr. Philipp Rostalski

Teacher:

- Institute for Electrical Engineering in Medicine

- Dr.-Ing. Hossameldin Abbas

Literature:

- Karel J. Keesman: System Identification: An Introduction - Springer-Verlag London Limited 2011
- Lennart Ljung and Torkel Glad: Modeling of Dynamic Systems - Prentice Hall 1994
- Lennart Ljung: System Identification - Theory for the User - Prentice Hall 1999

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- none

Module Exam(s):
- CS4480-L1: System Identification, Oral Examination, 100% of module grade

CS4504-KP08 - Cyber Physical Systems (CPS8)

Duration:	Turnus of offer:	Credit points:
2 Semester	each year, can be started in winter or summer semester	8

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (optional subject), Additionally recognized elective module, Arbitrary semester

Classes and lectures:

- CS5150 T: Organic Computing (lecture with exercises, 3 SWS)
- CS5153 T: Wireless Sensor Networks (lecture with exercises, 3 SWS)

Workload:

- 130 Hours private studies
- 90 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- basic principles of organic computing / self-x system properties
- from motion to intelligent behavior and system/machine behavior
- design for self-organization, robustness, adaptivity, flexibility, trust
- analyzing, reverse-engineering, debugging machine behavior
- designing experiments and measuring behavior
- modeling system/machine behavior
- complexity, opacity, obscurity, trust of (AI) systems and explainable AI
- architecture of organic computing systems
- applications of self-x systems
- basics of wireless sensor networks
- hardware aspects of sensor nodes
- physics and protocols of wireless communication
- routing in wireless networks
- time synchronization and localization in wireless networks
- data management and data processing in wireless sensor networks
- applications of wireless sensor networks

Qualification-goals/Competencies:

- Students are able to utilize the principles of organic computing/self-x systems on exemplary designs.
- They are able to explain principles of organic computing/self-x systems.
- They are able to analyze system/machine behaviors in a structured, sound approach.
- Students are able to present the pros and cons of sensor networks.
- They are able to cope with analysis, design, and evaluation of protocols in sensor networks.
- They are able to interpret and pursue current research activities for sensor networks.

Grading through:

- Oral examination

Responsible for this module:

- Prof. Dr.-Ing. Mladen Berekovic

Teacher:

- Institute of Computer Engineering

- Dr. rer. nat. Javad Ghofrani

Literature:

- C. Müller-Schloer, S. Tomforde: Organic Computing Technical Systems for Survival in the Real World - Birkhäuser, 2017
- H. Karl, A. Willig: Protocols and Architectures of Wireless Sensor Networks - Wiley, 2005

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises as specified at the beginning of the semester.

Module Exam(s):
- CS4504-L1: Cyber Physical Systems, oral exam, 100% of module grade.

CS4514-KP12 - Intelligent Agents (IntAgents)

Duration:	Turnus of offer:	Credit points:
1 Semester	each winter semester	12

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (optional subject), Additionally recognized elective module, 1st to 3th semester
- Certificate in Artificial Intelligence (compulsory), Artificial Intelligence, 1st semester
- Master Entrepreneurship in Digital Technologies 2020 (advanced module), technology field computer science, Arbitrary semester
- Master Computer Science 2019 (optional subject), Canonical Specialization Data Science and AI, 1st or 2nd semester
- Master IT-Security 2019 (advanced module), Elective Computer Science, 1st or 2nd semester
- Master Computer Science 2019 (optional subject), advanced module, Arbitrary semester

Classes and lectures:

- CS4514-P: Lab course Intelligent Agents (practical course, 2 SWS)
- CS4514-V: Intelligent Agents (lecture with exercises, 6 SWS)

Workload:

- 195 Hours private studies
- 120 Hours in-classroom work
- 45 Hours exam preparation

Contents of teaching:

- Agents, Mechanisms, and Collaboration: Intelligent agents and artificial intelligence / Game theory and social choice / Mechanism design, algorithmic mechanism design / Agent collaboration, rules of encounter / Continuous Space / Epistemic logic / Knowledge and seeing / Knowledge and time / Dynamic epistemic logic / Knowledge-based programs
- Perception (Language and Vision): Information retrieval and web-mining agents / Probabilistic dimension reduction, latent content descriptions, topic models, LDA, LDA-HMM / Representation learning for sequential structures, embedding spaces, word2vec, CBOW, skip-gram, hierarchical softmax, negative sampling / Language models (1d-CNNs. RNNs, LSTMs, ELMo, Transformers, BERT, GPT-3/OPT, and beyond), Natural language inference and query answering / Computer Vision (2D-CNNs, Deep Architectures: AlexNet, ResNet) /Combining language and vision (CLIP (OpenAI) / LIT (Google) / data2vec (Facebook) / Flamingo (DeepMind), DALL-E and beyond) /Knowledge graph embedding with GNNs, combining embedding-based KG completion with probabilistic graphical models(ExpressGNN, pLogicNet), MLN inference and learning based on embedded knowledge graphs, GMNNs)
- Planning, Causality, and Reinforcement Learning: Planning and acting with deterministic models, temporal models, nondeterministic models, probabilistic models / Standard decision making / Advanced decision making and reinforcement learning / Causal dependencies / Intervention / Instrumental variables / Counterfactuals / Causal planning / Causal reinforcement learning
- In the project lab students use the usual (open source) data science related programming languages and tools in order to transfer the abstractions, concepts and results taught in the lecture into concrete software models and artefacts to be applied on big data.

Qualification-goals/Competencies:

- The students can enumerate central ideas, define the relevant concepts and explain the functioning of algorithms with help of application scenarios for all the items listed in contents of teaching.

Grading through:

- Oral examination

Responsible for this module:

- Prof. Dr.-Ing. Nele Rußwinkel

Teacher:

- Institute of Information Systems
- Prof. Dr.-Ing. Nele Rußwinkel

Literature:

- J. Pearl, C. Glymour, and N.P. Jewell: Causal Inference in Statistics - A Primer - Wiley, 2016
- Y. Shoham, K. Leyton-Brown: Multiagent-Systems: Algorithmic, Game-Theoretic, and Logical Foundations - Cambridge University Press, 2009
- S.J. Russell, P. Norvig: Artificial Intelligence: A Modern Approach - Pearson, 2020
- M. Ghallab, D. Nau, P. Traverso: Automated Planning and Acting - Cambridge University Press, 2016

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- successful completion of the Lab Course Intelligent Agents CS4514-P

Module examination(s):
- CS4514-L1: Intelligent Agents, oral examination, 100% of module grade.

(Replaces CS4513-KP12).

CS4521-KP12 - Constructive Cognitive Science (CCS)

Duration:	Turnus of offer:	Credit points:
2 Semester	each semester	12

Course of study, specific field and term:

- Master Computer Science 2019 (optional subject), advanced module, Arbitrary semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Additionally recognized elective module, 1st to 3th semester

Classes and lectures:

- Human-Aware AI (lecture, 3 SWS)
- Models for human intelligent Assistance (lecture, 3 SWS)
- Human-Aware AI (Excercises with project, 3 SWS)

Workload:

- 135 Hours in-classroom work
- 105 Hours private studies
- 90 Hours work on project
- 30 Hours exam preparation

Contents of teaching:

- Definition and Examples for Human-Centered and Human-Aware AI systems
- Constructive Cognitive Science, Situation understanding and mental models
- Explainable Human-AI Interaction
- Cognitive Modelling especially cognitive architectures
- Human-Robot Collaboration
- Digital cognitive Twins and Physical Human Models
- Intention recognition and Theory of Mind
- Interactive task learning
- Situated cognitive agents
- Tracing the cognitive state of the human-in-the-loop

Qualification-goals/Competencies:

- The students can enumerate central ideas, define the relevant concepts and explain the functioning of algorithms with help of application scenarios as well as apply the algorithms for all the items listed in contents of teaching.

Grading through:

- exercises and project assignments
- Oral examination

Responsible for this module:

- Prof. Dr.-Ing. Nele Rußwinkel

Teacher:

- Institute of Information Systems

- Prof. Dr.-Ing. Nele Rußwinkel

Literature:

- S.J. Russell: Human Compatible: Artificial Intelligence and the Problem of Control - Penguin Books, 2020
- C.S. Nam, J.-Y. Jung, S. Lee (Eds.): Human-Centered Artificial Intelligence: Research and Applications - Elsevier, 2022
- J.R. Anderson: How Can the Human Mind Occur in the Physical Universe? - Oxford University Press, 2007
- B. Sneiderman: Human-Centered AI - Oxford University Press, 2022

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises and project tasks as specified at the beginning of the semester.

Module Exam(s):
- CS4505-L1: Constructive Cognitive Science, oral exam, 100% of the module grade.

CS4702-KP06 - Computer Security (CoSec)

Duration:	Turnus of offer:	Credit points:
1 Semester	normally each year in the summer semester	6

Course of study, specific field and term:

- Master Entrepreneurship in Digital Technologies 2020 (advanced module), technology field computer science, Arbitrary semester
- Master Media Informatics 2020 (optional subject), computer science, Arbitrary semester
- Master Medical Informatics 2019 (optional subject), ehealth / infomatics, 1st or 2nd semester
- Master IT-Security 2019 (optional subject), IT Security and Privacy, 1st, 2nd, or 3rd semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Additionally recognized elective module, Arbitrary semester

Classes and lectures:

- Computer Security (lecture, 2 SWS)
- Computer Security (practical course, 3 SWS)

Workload:

- 85 Hours private studies
- 75 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Applied cryptography in systems and protocols: Overview of common methods and their applications
- Efficient and secure implementation of common crypto procedures: multiple-precision arithmetic, efficient exponentiation, constant time algorithms etc.
- Physical implementation attacks and countermeasures: Error injection attacks, passive physical attacks such as SPA/DPA and timing attacks, modern inference methods and associated cryptanalysis methods, classes of protective measures
- Virtualization security and microarchitecture attacks: security concepts in the operating system and hypervisor, microarchitecture attacks such as cache attacks, spectre, etc., measures to restore system security
- Trusted computing and hardware-assisted system security: How TPMs, Secure Elements and Trusted Execution work environments, basics and cryptographic techniques, design basics for secure systems

Qualification-goals/Competencies:

- The students can demonstrate a deep understanding of cryptographic methods and their applications in communication systems.
- They can construct secure and efficient cryptographic primitives and implement them securely in computer systems.
- They can explain methods and algorithms for efficient multiple-precision arithmetic.
- They can perform basic side-channel attacks on systems with physical access or shared systems with code execution rights.
- They can implement protection against specific physical attacks for cryptographic primitives.
- They can evaluate the security of existing primitives.

Grading through:

- Viva Voce or test
- written homework

Requires:

- Cybersecurity (CS2250-KP04)

Responsible for this module:

- Prof. Dr. Thomas Eisenbarth

Teacher:

- Institute for IT Security
- Prof. Dr. Thomas Eisenbarth

Literature:

- S. Mangard, E. Oswald & T. Popp: Power analysis attacks: Revealing the secrets of smart cards - Vol. 31, Springer Science & Business Media, 2008
- D. Stinson: Cryptography: Theory and Practice - 4th ed., CRC Press, 2018
- : Recent literature

Language:

- English, except in case of only German-speaking participants

Notes:

Admission requirements for taking the module:
- None (the competencies under

CS4703-KP06 - Advanced Cryptology (AdvCrypto)

Duration:	Turnus of offer:	Credit points:
1 Semester	every summer semester	6

Course of study, specific field and term:

- Master Computer Science 2019 (optional subject), Elective, Arbitrary semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Additionally recognized elective module, Arbitrary semester
- Master CLS 2016 (optional subject), computer science, 3rd semester
- Master IT-Security 2019 (optional subject), IT Security and Privacy, Arbitrary semester

Classes and lectures:

- Lecture Advanced Cryptoplogy (lecture, 3 SWS)
- Exercise Advanced Cryptoplogy (seminar-style lectures with exercises, 1 SWS)

Workload:

- 100 Hours private studies
- 60 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Concrete security and asymptotic security: comparison of both approaches in relation to modes of operations
- Block-Ciphers: Feistel Networks, Substitution-Permutation Networks, Design Principles, Linear Cryptanalysis, Differential cryptanalysis
- Authenticated Encryption
- Secure multi-party calculations: preprocessing model, protection of algorithms against side-channel attacks, MPC-in-the-Head (for ZK evidence)
- Obfuscation: Nicht-Machbarkeit (BlackBox), Machbarkeit (indistinguishable Obfuscation)

Qualification-goals/Competencies:

- The participants can explain and use basic theoretic cryptographic objects
- They are able to understand current concepts of cryptography
- They show a deep understanding of cryptographic methods
- They understand the basic connection between theoretical and practical aspects of cryptography
- They are able to understand current scientific works about cryptography and explain them

Grading through:

- Written or oral exam as announced by the examiner
- written homework

Requires:

- Cryptology (CS3420-KP04, CS3420)

Responsible for this module:

- Prof. Dr. Thomas Eisenbarth

Teacher:

- Institute for IT Security

- Dr Sebastian Berndt

Literature:

- Katz, Lindell: Introduction to Modern Cryptography - 2nd ed., CRC Press, 2014
- Cramer, Damgård, Nielsen: Secure Multiparty Computation and Secret Sharing - 1st ed., Cambridge University Press, 2015
- Barak: An Intensive Introduction to Cryptography - Lecture Notes

Language:

- English, except in case of only German-speaking participants

Notes:

Admission requirements for taking the module:
- None (the competencies under

CS4705-KP06 - Cryptographic Engineering (CryEng)

Duration:	Turnus of offer:	Credit points:
1 Semester	every summer semester	6

Course of study, specific field and term:

- Master Entrepreneurship in Digital Technologies 2020 (advanced module), technology field computer science, Arbitrary semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Additionally recognized elective module, Arbitrary semester
- Master Computer Science 2019 (optional subject), Elective, Arbitrary semester
- Master IT-Security 2019 (optional subject), IT Security and Privacy, 1st, 2nd, or 3rd semester

Classes and lectures:

- Cryptographic Engineering (lecture, 2 SWS)
- Cryptographic Engineering (exercise, 2 SWS)

Workload:

- 100 Hours private studies
- 60 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Efficient Implementation of Finite Field Arithmetic for cryptographic Applications.
- Stream Ciphers: Design and hardware Implementation.
- Block Ciphers: Design, hardware Implementation, and Lightweight Encryption Algorithms.
- Hash Functions: Design and hardware Implementation.
- Public-Key Cryptography over GF(2m): Design and Implementation.
- True and Pseudo Random Number Generators (TRNG): Design, test, and hardware Implementation.
- Physical Unclonable Functions (PUFs): Design Challenges and Hardware- Architectures.

Qualification-goals/Competencies:

- Students will become familiar with the concept of cryptographic engineering and the associated topics with it.
- They can expand and enhance their knowledge about a cryptography and applied cryptography.
- They can become more familiar with the concepts of hardware-security.
- They can learn efficient implementation of Finite Field Arithmetic in hardware and its applications in cryptography.
- They can learn the techniques for hardware-implementation of cryptographic algorithms
- They can demonstrate a deep understanding of several structures and designs of stream and block ciphers
- They can take an advanced step towards hardware and physical security such as TRNG, PUFs.

Grading through:

- written exam

Requires:

- Cryptology (CS3420-KP04, CS3420)

Responsible for this module:

- Prof. Dr.-Ing. Mladen Berekovic

Teacher:

- Institute of Computer Engineering
- Dr.-Ing. Saleh Mulhem

Literature:

- Ferguson, Niels, Bruce Schneier, and Tadayoshi Kohno: Cryptography Engineering: Design Principles and Practical Applications - 2012
- Koç Ç.K.: Cryptographic Engineering - Springer, Boston, MA, (2009)
- Wachsmann, Christian, and Ahmad-Reza Sadeghi: Physically unclonable functions (PUFs): Applications, models, and future directions - Morgan & Claypool Publishers, 2014
- Johnston, David: Random Number Generators Principles and Practices: A Guide for Engineers and Programmers - Walter de Gruyter GmbH & Co KG, 2018

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- Successful completion of exercises as specified at the beginning of the semester.

Module examination(s):
- CS4705-L1: Cryptographic Technology, written exam, 90min, 100% of module grade.

CS4720-KP06 - Energy Efficiency in Emebedded Systems (EEE)

Duration:	Turnus of offer:	Credit points:
1 Semester	every summer semester	6

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (module part), Additionally recognized elective module, Arbitrary semester
- Master Computer Science 2019 (optional subject), Elective, Arbitrary semester

Classes and lectures:

- Energy Efficiency in Emebedded Systems (lecture, 2 SWS)
- Energy Efficiency in Emebedded Systems (exercise, 2 SWS)

Workload:

- 85 Hours private studies and exercises
- 70 Hours in-classroom work
- 25 Hours exam preparation

Contents of teaching:

- Motivation and power dissipation on semiconductor level
- Power dissipation of digital circuits, inparticular CMOS
- Power Management in Hard- and Software (Sleep Modes, DVS, FS, Undervolting)
- Energy efficient system design (applications)
- Energy Harvesting and Transiently Powered Computing (TPC)

Qualification-goals/Competencies:

- students will have a deeper understanding of hardware and software mechanisms for evaluating and developing energy-efficient embedded systems
- They have a deeper understanding of the electrotechnical basics of power dissipation in digital systems
- They can analyze the power dissipation of systems at any level and apply appropriate methods to increase efficiency
- They can use a variety of standard techniques to achieve
- They can model and evaluate energy-autonomous systems

Grading through:

- Written or oral exam as announced by the examiner

Responsible for this module:

- Prof. Dr.-Ing. Mladen Berekovic

Teacher:

- Institute of Computer Engineering

- Dr. Ulf Kulau

Literature:

- Ulf Kulau: Course: Energy Efficiency in Embedded Systems A System-Level Perspective for Computer Scientists - EWME, 2018
- David Harris and N. Weste: CMOS VLSI Design ed. - Pearson Education, 2010
- Jan Rabaey: Low Power Design Essentials (Integrated Circuits and Systems) - Springer, 2009

Language:

- English, except in case of only German-speaking participants

Notes:

Prerequisites for attending the module:
- None

Prerequisites for the exam:
- Successful completion of practice and project assignments during the semester.

CS5195-KP04 - Current Topics in IT Security (AktTheITS)

Duration:	Turnus of offer:	Credit points:
1 Semester	each semester	4

Course of study, specific field and term:

- Master Computer Science 2019 (optional subject), Elective, Arbitrary semester
- Master IT-Security 2019 (compulsory), IT-Security, 3rd semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Additionally recognized elective module, Arbitrary semester

Classes and lectures:

- Current Topics IT Security and Reliability (seminar-style lectures, 2 SWS)
- Current Topics IT Security and Reliability (project work, 1 SWS)

Workload:

- 45 Hours work on project
- 45 Hours in-classroom work
- 30 Hours private studies and exercises

Contents of teaching:

- new results in cyber security
- design and implementation of a secure system for a complex application and its security analysis

Qualification-goals/Competencies:

- deeper knowledge of current developments in IT security
- professional experience of constructing and analyzing computer systems and networks with respect to security issues

Grading through:

- Oral examination

Responsible for this module:

- Prof. Dr. Thomas Eisenbarth

Teacher:

- Institute for IT Security
- Institute for Theoretical Computer Science

- Prof. Dr. Maciej Liskiewicz
- Prof. Dr. Rüdiger Reischuk
- Prof. Dr. Thomas Eisenbarth
- Prof. Dr. Esfandiar Mohammadi

Literature:

- papers to be discussed depend on specific topics: -

Language:

- English, except in case of only German-speaking participants

Notes:

Admission requirements for taking the module:
- None

Admission requirements for participation in module examination(s):
- alternates, will be announced at the beginning of the semester

Module Exam(s):
- CS5195-L1: Current Topics in IT Security, oral exam, 100% of module grade.

In the winter semester, the organization and teaching are carried out by ITS, with Professor Thomas Eisenbarth in charge.

In the summer semester, the organization and teaching are carried out by TCS, with Professor Rüdiger Reischuk holding the responsibility.

MA4030-KP08, MA4030 - Optimization (Opti)

Duration:	Turnus of offer:	Credit points:
1 Semester	each summer semester	8

Course of study, specific field and term:

- Minor in Teaching Mathematics, Bachelor of Arts 2023 (compulsory), mathematics, 8th semester
- Bachelor CLS 2023 (compulsory), mathematics, 4th semester
- Master Auditory Technology 2022 (optional subject), mathematics, 2nd semester
- Master MES 2020 (optional subject), mathematics / natural sciences, Arbitrary semester
- Bachelor Computer Science 2019 (optional subject), Extended optional subjects, Arbitrary semester
- Master Robotics and Autonomous Systems 2019 (optional subject), Additionally recognized elective module, Arbitrary semester
- Minor in Teaching Mathematics, Bachelor of Arts 2017 (compulsory), mathematics, 8th semester
- Master Auditory Technology 2017 (optional subject), mathematics, 1st or 2nd semester
- Bachelor Computer Science 2016 (optional subject), advanced curriculum, Arbitrary semester
- Bachelor CLS 2016 (compulsory), mathematics, 4th semester
- Master MES 2014 (optional subject), mathematics / natural sciences, Arbitrary semester
- Master MES 2011 (optional subject), mathematics, 2nd semester
- Master Computer Science 2012 (optional subject), advanced curriculum numerical image processing, 2nd or 3rd semester
- Bachelor MES 2011 (optional subject), medical engineering science, 6th semester
- Master Computer Science 2012 (optional subject), advanced curriculum analysis, 2nd or 3rd semester
- Bachelor CLS 2010 (compulsory), mathematics, 4th semester

Classes and lectures:

- Optimization (lecture, 4 SWS)
- Optimization (exercise, 2 SWS)

Workload:

- 130 Hours private studies and exercises
- 90 Hours in-classroom work
- 20 Hours exam preparation

Contents of teaching:

- Linear optimization (simplex method)
- Unconstrained nonlinear optimization (gradient descent, conjugate gradients, Newton method, Quasi-Newton methods, globalization)
- Equality- and inquality-constrained nonlinear optimization (Lagrange multipliers, active set methods)
- Stochastic methods for machine learning

Qualification-goals/Competencies:

- Students can model real-life problems as optimization problems.
- They understand central optimization techniques.
- They can explain central optimization techniques.
- They can compare and assess central optimization techniques.
- They can implement central optimization techniques.
- They can assess numerical results.
- They can select suitable optimization techniques for practical problems.
- Interdisciplinary qualifications:
- Students can transfer theoretical concepts into practical solutions.
- They are experienced in implementation.
- They can think abstractly about practical problems.

Grading through:

- Written or oral exam as announced by the examiner

Is requisite for:

- Non-smooth Optimization and Analysis (MA5035-KP05)

Requires:

- Linear Algebra and Discrete Structures 2 (MA1500-KP08, MA1500)
- Analysis 2 (MA2500-KP09)
- Analysis 2 (MA2500-KP04, MA2500)

Responsible for this module:

- Prof. Dr. rer. nat. Jan Modersitzki

Teacher:

- Institute of Mathematics and Image Computing

- Prof. Dr. rer. nat. Jan Modersitzki
- Prof. Dr. rer. nat. Jan Lellmann

Literature:

- J. Nocedal, S. Wright: Numerical Optimization - Springer
- F. Jarre: Optimierung - Springer
- C. Geiger: Theorie und Numerik restringierter Optimierungsaufgaben - Springer

Language:

- offered only in German

Notes:

Prerequisites for attending the module:
- None (Familiarity with the topics of the required modules is assumed, but the modules are not a formal prerequisite for attending the course).

Prerequisites for the exam:
- Examination prerequisites can be defined at the beginning of the semester. If preliminary work is defined, it must have been completed and positively evaluated before the first examination.

Examination:
- MA4030-L1: Optimization, written examination (90 min) or oral examination (30 min) as decided by examiner, 100 % of final mark

RO5803-KP04 - Rescue Robotics (RR)

Duration:	Turnus of offer:	Credit points:
1 Semester	each winter semester	4

Course of study, specific field and term:

- Master Robotics and Autonomous Systems 2019 (optional subject), Additionally recognized elective module, Arbitrary semester

Classes and lectures:

- RO5803-V: Rescue Robotics (lecture, 2 SWS)
- RO5803-Ü: Rescue Robotics (exercise, 2 SWS)

Workload:

- 60 Hours private studies
- 60 Hours in-classroom work

Contents of teaching:

- Special requirements for disaster management and response and the resulting consequences on rescue robot design.
- Information structures for rescue systems
- Information exchange between rescue robots
- Command and control systems for search and rescue robots
- Tactical communication for cooperative SAR robot missions as well as interoperability in heterogeneous teams.
- Design guidelines for human interfaces to rescue robots
- Casualty and vital sign detection in rescue scenarios
- Medical assistance at the scene of incident and determination of vital signs
- Evaluation and benchmarking of SAR robots

Qualification-goals/Competencies:

- The students can apply the tools to program and simulate mobile rescue robots. They have developed a good overview about mobile robotics, localization and path planning in difficult scenarios.
- The students have knowledge about the work and command structures of rescue personell and the requirements on control, communcation and interaction of rescue robots with the personnel.
- The students have developed a notion of medical first response by rescue personnel as well as technical solutions to locate missing persons, determine vital signs and realize medical assistance at the scene of incident.

Grading through:

- Oral examination

Teacher:

- Institute for Robotics and Cognitive Systems

- Prof. Dr. rer. nat. Floris Ernst

Language:

- offered only in English

Notes:

Admission requirements for taking the module:
- None

Entry requirements for taking module examination(s):
- RO5803: Rescue Robotics - Successful completion of exercises as specified at the beginning of the semester.

Module Exam(s):
RO5803-L1: Rescue Robotics, oral examination, 100% of module grade