Module handbook

for the study program
Master of Science in Autonomous Systems
at the Sankt Augustin campus of

Bonn-Rhein-Sieg
University of applied sciences

Department of Computer Science

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1 Module group “Core Courses” (CC)

Advanced Software Technology

Module group and semester	MAS, 1. Semester, Core Courses (CC)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Gerhard Kraetzschmar
Teacher	Prof. Dr. Gerhard Kraetzschmar Dr. Björn Kahl
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	Ability to develop algorithmic solutions for problems. Good programming abilities in object-oriented languages Java and C++. Ability to use standard software development tools and IDEs like Eclipse.
Learning targets	Professional competency: Knowledge of libraries, tools, and software patterns relevant for solving advanced programming problems in distributed computing. Methodological competency: Ability to apply advanced programming concepts and techniques in general contexts. Ability to design software for distributed systems. Ability to apply these concepts to problems in robotics. Individual Competency: Ability to get quickly acquainted with large software libraries and new tools. Ability to test and debug software applying the learned concepts.
Content	The course covers the following topics in-depth: – advanced data structures: sets, heaps, dictionaries, hashtables – files, streams, and I/O – templates and generics – processes and threads – inter-process and network communication: sockets, UDP, TCP/IP – middleware: CORBA, ICE, ZeroMQ – component-based programming – model-based software development: UML, Realtime-UML, MDA Furthermore, the following topics will be included depending on time: – foreign language interfaces: C, Python, Prolog – GUI programming – web technologies: XML
Passing requirements	Homeworks and Examination

Form der Studien-leistung	Participants have to solve example problems in homework assignments. The final examination can either be oral, in writing, or by submitting a term project.
Media	Slides, whiteboard, online demonstrations. Moodle supported.
Literature	– Deitel & Deitel: C++: How to Program, Pearson Education Limited, 2011 – Deitel & Deitel: Java: How to Program, Prentice Hall International, 2004 – Gamma, Helm, Johnson, Vlissides: Design Patterns, Addison Wesley, 2005 – Kuchana: Software Architecture Design Patterns in Java, Auerbach Publication, 2004 – McConnell: Code Complete 2, Microsoft Press, 2004 – Tanenbaum: Distributed Systems, Principles and Paradigms, 2nd edition, Prentice Hall International, 2006

Autonomous Mobile Robots

Module group and semester	MAS, 1. Semester, Core Courses (CC)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Erwin Prassler
Teacher	Dr. Björn Kahl
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	Bachelor of CS-level knowledge in mathematics and computer science, fluency in object-oriented programming in C++
Learning targets	Professional competency: The students know basic and advanced concepts of robotics and sensorimotor systems, and essential concepts and techniques for mobility, navigation and robot control. The students know important properties and (dis)advantages of different drive systems and sensor, know principles and limits of mapping and path planning algorithms. Methodological competency: The students can structure a complex (software) problem like an mobile robot controller architecture into modules and subtasks and model the relationships between system components. They are able to select and implement appropriate methods to tackle common mobile robot tasks. They can evaluate and understand the strengths and limits of different mapping, navigation or planning algorithms in a given task scenario. They can systematically implement and test a system using modern software engineering techniques. Individual competency: Strong problem-structuring and solving skills, proficiency in analytical (“top-down”) problem decomposition. Efficient team team-oriented software development under tight time constraints.
Content	• Structure of autonomous mobile robots • Locomotion • Kinematics • Sensors and actuators • Hardware components for mobile robots • Exploration and mapping • Self-localization and SLAM

	• Path planning and execution • Navigation and obstacle avoidance
Passing requirements	Homeworks and Examination
Expected study efforts	Active participation in lectures and lab, solution of homework exercises (50% must be correct), programming of robots, designing and performing experiments, oral or written examination.
Media	Slides, blackboard, multimedia material, demonstrations with simulated robots
Literature	Textbook • Siegwart & Nourbakhsh: Introduction to Autonomous Mobile Robots. MIT Press, 2004. Supplementary: • Thrun & Burgard & Fox: Probabilistic Robotics. MIT Press, 2005. • Arkin: Behavior-Based Robotics. MIT Press, 1998. • Murphy: Introduction to AI Robotics. MIT Press, 2000. • Nehmzow: Mobile Robots: A Practical Introduction. Springer, 2000. • Jones & Flynn & Seiger: Mobile Robots. AK Peters, 1999.

Mathematics for Robotics and Control

Module group and semester	MAS, 1. Semester, Core Courses (CC)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Paul Plöger
Teacher	Prof. Dr. Paul Plöger
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	good knowledge in linear algebra and analysis, fluent knowledge in some mathematical scripting language, preferably MATLAB/SIMULINK
Learning targets	Professional competency: Knowing and understanding modeling principles; knowing and understanding basic problems and requirements for robust control, knowledge and understanding of mathematical concepts behind simulation. methodological competency: Apply coherent solution principles, be able to structure and abstract. Ability to model / simulate / control typical sample problems in mobile robotics, apply theoretical principles to restricted sample problems. Transfer insights from models to more realistic systems. Individual competency: Strong problem-solving skills using mathematical methods, proficiency in handling of mathematical concepts, notations, and argumentations.
Content	Modern design flows for the programming of robotic systems require the modeling and simulation of systems in order to develop stable control and filtering algorithms. This course will lay the necessary foundations in modeling based on primarily linear system theory, then performing numerical simulation based on real world parameterized models and finally development of robust control algorithms. Exercises will be solved using the MATLAB/SIMULINK programming environment.
Passing requirements	Homeworks and Examination
Expected study efforts	Active participation in lectures, solution of homework exercises. 80% submissions are required, 50% must be correct, passing all written examination(s). There will be drill, advanced and programming exercises.
Media	Lecture using predominantly visual media, on the blackboard, exercises, interactive learning platform, educational articles, and technical writings like application notes

Literature	• Press & Teukolsky & Vetterling & Flannery: Numerical Recipes in C++, 2nd edition. Cambridge Univ. Press, 2002. • Kwakernaak & Sivan: Linear Optimal Control Systems. Willey interscience, 1972, available online (http://www.ieeecss.org/PAB/classics/). • Kailath: Linear Systems. Prentice Hall, 1980. • Choset et.al.: Principles of Robot Motion. MIT Press, 2005. • Khalil: Nonlinear Systems. Prentice Hall, 2002

Principles of Cognitive Robots

Module group and semester	MAS, 1. Semester, Core Courses (CC)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Erwin Prassler
Teacher	Prof. Dr. Erwin Prassler Prof. Dr. Gerhard Kraetzschmar
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	B.S.-level knowledge of computer science, especially knowledge of data structures and algorithms, and computational complexity.
Learning targets	Professional competency: Knowing and understanding basic concepts and architectures in Artificial Intelligence, such as search algorithms, different types of logics (predicate logic, first-order logic, temporal logics, and modal logics) and reasoning and knowledge representation methods. Methodological competency: The students can apply concepts and architectures for artificial intelligence-based systems in practice. They are able to evaluate and select appropriate methods from several options to solve control problems in intelligent robotics. Individual competency: Strengthened ability to logical arguing and reasoning. Understanding technological, economic and social aspects of contemporary artificial intelligence and its limits. Being able to argue for or against application of AI methods to real world problems under technological, economic and other constraints.
Content	– Intelligent Agents – Search methods (Basics, Informed Search, Adversial Search Methods) – Constraint Satisfaction Problems – Logics (Propositional, First Order, Logic Programming) – Knowledge Representation: Conceptualization, Ontologies, Description Logics – Survey of Agent Architectures
Passing requirements	Homeworks and Exam
Expected study efforts	Active participation in class. Solution of homework exercises. Performing and documenting experiments. Examination.
Media	Slides, whiteboard, online demonstrations. Moodle supported.

Literature	Textbook: – Russell & Norvig: Artificial Intelligence – A Modern Approach, 2nd edition. Prentice Hall, 2002. Supplementary: – Baader, Calvanese, McGuinness, and Nardi: The Description Logic Handbook. Cambridge University Press, 2007. – John Sowa: Knowledge Representation: Logical, Philosophical, and Computational Foundations. MIT Press, 2000. – Robin Murphy: Introduction to AI Robotics. MIT Press, 2000.

2 Module group “Specialization *Robot Systems Design*” (PRSD)

Advanced Control Methods

Module group and semester	MAS, 2. Semester, Specialization “Principles of Robotics Systems Design” (PRSD)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Paul Plöger
Teacher	Prof. Dr. Paul Plöger
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	An understanding of system theory, basics of physical robot models (kinematic and dynamic), ODE foundations, linear algebra foundations, all which have been coverd in the core course Mathematics for Robotics and Control
Learning targets	Professional competency: Knowing and understanding control principles; knowing and understanding basic problems and requirements for robust control, knowledge and understanding of mathematical concepts behind failures, diagnostics and failure removal. Methodological competency: Apply coherent solution principles, be able to structure and abstract. Ability to formalize typical control problems in mobile manipulation, apply theoretical principles to restricted sample problems. Transfer insights from easy models to realistic systems. Individual competency: Strong problem-solving skills using mathematical methods, proficiency in handling of mathematical concepts, notations, and argumentations.
Content	1. Elements of Linear System Theory 2. Analysis of Linear Control Systems 3. Optimal Linear State Feedback Control Systems 4. Optimal Linear Reconstruction of the State 5. Optimal Linear Output Feedback Control Systems 6. Linear Optimal Control Theory for Discrete-Time Systems 7. Robust control 8. Failure detection isolation and removal

Passing requirements	completion of the placement tests, written final examination
Expected study efforts	Active participation in lectures, solution of homework exercises. 50% submissions are required as, 50% of the points have to be reached. There will be drill, advanced and project-like assignments.
Media	Lecture using predominantly visual media, on the blackboard, exercises, interactive learning platform (MOODLE or Ilias), educational articles, and technical writings like application notes, experiments on real HW.
Literature	• Huibert Kwakernaak, Raphael Sivan, Linear Optimal Control Systems, Wiley Interscience, NY, 1972 • Rolf Isermann, Fault-Diagnosis Systems, Springer, 2006. • Kai Müller, Entwurf robuster Regelungen, Teubner, 1996.

Hardware/Software Co-Design

Module group and semester	MAS, 2. Semester, Specialization “Principles of Robotics Systems Design” (PRSD)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Paul Plöger
Teacher	Prof. Dr. Paul Plöger
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	Basic knowledge in hardware related programming and SW components like low level interfaces and sensors.
Learning targets	Professional competency: Knowing and understanding the workings of advanced sensors like aVLSI or CSEM camera, low level microcontroller architectures, interface standards and their usage, signals and signal processing, reprogrammable HW and the evolution of it; knowing and understanding system design of robots, interfacing techniques, working principles of sensors. Methodological competency: Gain insight in coherent interfacing principles, decompose complex systems and let components collaborate; application of principles to restricted sample problems, transfer to more realistic ones. Individual competency: Build up problem consciousness for building and programming autonomous robots.
Content	HW/ SW Co-Design deals with the question, which parts of an algorithm should go into software, which should go into hardware. In nowadays sensor industry we observe the tendency, to make sensors more and more ’intelligent’ by adding more and more processing power close to the sensors itself. Now when building a mobile robotic systems the question arises what should be casted in to HW for speed, reliability, energy or architectural reasons and what is better kept the ’flexible’ form of SW. Profiling techniques to build a sound basis for a decision are used. We start with various examples of the working of sensors and its possible signal shapes, conditioning and coding like analog/digital or PWM. We study, what functionality may be realized ’close to the sensor’ today. Then well cover interface techniques at hand of examples like serial links, USB, CAN and one high speed bus. Then we study biologically inspired ways of signal processing and finally look at the possibility to use global optimization strategies from nature (i.e. evolution) for the generation of HW. The foundations of this lecture lay in the area of sensors, signal processing, microcontrollers and hardware design.

Passing requirements	Homework and Examination
Expected study efforts	Active participation in lectures, solution of homework exercises. 80% submissions are required. 50% of the points have to be reached. There will be drill, advanced and programming exercises.
Media	Lecture using predominantly visual media, on the blackboard, exercises, interactive learning platform, educational articles, and technical writings like application notes, experiments on real HW.
Literature	• Nolfi & Floreano: Evolutionary Robotics. MIT Press, 2004. • Catsoulis: Designing Embedded Hardware. O'Reilly, 2002. • Jones & Flynn & Seiger: Mobile Robots. AK Peters, 1999. • Pfeiffer & Scheier: Understanding Intelligence. MIT Press, 2000. • Gockel & Dillmann: Embedded Robotics. Elektor-Verlag, 2005

Mobile Manipulation

Module group and semester	MAS, 2 Semester, Specialization “Principles of Robotics Systems Design” (PRSD)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Erwin Prassler
Teacher	Prof. Dr. Erwin Prassler Prof. Dr. Paul Plöger Dr. Björn Kahl
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	Knowledge in robot manipulation, mobile robotics, robot perception, control architecture
Learning targets	Professional competency: Design and implementation of new (service) robot applications enabled by mobile manipulation technology. Methodological competency: Knowledge of mobile manipulation algorithms; knowledge of control and coordination architectures and paradigms for mobile manipulation.
Content	• Motion planning for mobile manipulators • Path smoothing and adaptation • 3D perception and modeling • Control and coordination • Architectures for mobile manipulation • Robotic SDK for Mobile Manipulators
Passing require-ments	Exam
Expected study ef-forts	Active participation in lectures, solution of homework exercises, oral or written examination.
Media	Slides, whiteboard
Literature	• Steven M LaValle. Planning Algorithms. Cambridge, 2006. • Rosen Diankov. Automated Construction of Robotics Manipulation Programs. Robotics Institute, Carnegie Mellon University. 2010.

Robot Manipulation

Module group and semester	MAS, 2 Semester, Specialization "Principles of Robotics Systems Design" (PRSD)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Erwin Prassler
Teacher	Prof. Dr. Erwin Prassler Prof. Dr. Paul Plöger Dr. Björn Kahl
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	Basic knowledge in linear algebra and analysis, fluent knowledge in some programming language, some knowledge in C++ and MATLAB
Learning targets	Professional competency: Knowledge of the principles of robot manipulation. Understanding of basic mathematical and physical methods and models to describe, design and program robots for manipulation tasks. Methodological competency: Knowledge of kinematical descriptions. Understanding of concept of forward and backward kinematics (position, velocity, force) and motion in actuator space, joint space and Cartesian space. Individual competency: Ability to program a robot manipulation to perform a task including solution of inverse kinematic problems.
Content	1. History of robot manipulation, applications, and fundamental problems 2. Spatial descriptions and transformations 3. Manipulator kinematics 4. Inverse manipulator kinematics 5. Jacobians: velocities and static forces 6. Trajectory generation
Passing requirements	Homework and Examination
Expected study efforts	Active participation in lectures, solution of homework exercises, oral or written examination.

Media	Slides, whiteboard.
Literature	Textbook • Craig: Introduction to Robotics - Mechanics and Control. 2004. Supplementary • Siciliano, Sciavicco et al.: Robotics - Modelling, Planning, and Control, 2008. • Spong, Hutchinson, Vidyasagar: Robot Dynamics and Control, 2004.

Robot Navigation

Module group and semester	MAS, 2. Semester, Specialization "Principles of Robotics Systems Design" (PRSD)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Gerhard Kraetzschmar
Teacher	Dr. Björn Kahl Prof. Dr. Gerhard Kraetzschmar
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	Sound knowledge of linear algebra. Good programming skills in Java and C++. Solid knowledge of systematic and heuristic search algorithms.
Learning targets	Professional competency: Advanced understanding of the problem of pose recognition and navigation. Knowledge of state-of-the-art solution approaches to localization, path planning and motion planning. Methodological competency: The students are able to describe and program methods for map-building, pose estimation, path planning, and obstacle avoidance. Individual competency: Ability to cognitively grasp and reason about multi-dimensional spaces and trajectories therein. Improved abstract and mathematical thinking.
Content	– self-localization and state estimation – robot mapping and exploration, SLAM – potential field methods – grid-based methods, polygon-based methods – random tree-based approaches – collision detection and obstacle avoidance – navigation architectures – integration of navigation in robot control architectures
Passing requirements	Homeworks and Examination
Expected study efforts	Active participation in class. Solution of homework exercises. Performing and documenting motion planning experiments. Examination.
Media	Slides, whiteboard, online demonstrations. Moodle supported.
Literature	Textbook: – Thrun, Burgard, Fox: Probabilistic Robotics, MIT Press, 2005.

	– Latombe: Robot Motion Planning, Kluwer, 1990. Supplementary: – del Pobil, Serna: Spatial Representation and Motion Planning, Springer, 2008. – Ito: Robot Vision: Strategies, Algorithms, and Motion Planning, Nova Science, 2009.

Robot Systems Design

Module group and semester	MAS, 2. Semester, Specialization “Principles of Robotics Systems Design” (PRSD)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Erwin Prassler
Teacher	Prof. Dr. Erwin Prassler
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	Basic understanding of robot navigation and manipulation.
Learning targets	Professional competency: Derivation of system requirements and operation principles from intended application and/or task; development and implementation of overall system concept. Methodological competency: Application of established design methods to robotics. Systematic selection of best-suited components form available technology based on required functionalities, performances and desired cost-value relation.

Content	• design methodology
	• materials and their properties
	• morphological structures and variations in nature and engineering
	  – work space analysis
	  – kinematic configurations
	• actuation principles
	  – drive systems (basic principles, scaling)
	  – power transmission and gear mechanisms
	  – energy supply and management
	• sensing principles and sensors
	  – proprioceptive sensing
	  – exteroceptive sensing (vision, range, force & torque, . . .)
	• control concepts
	  – actuation control
	  – joint space control

	– work space control
	• system architecture
	  – modularity and component concepts
	  – buses and communication
	• user interface and programming

Passing requirements	Homework and Examination.
Expected study efforts	Active participation in lecture and lab class. Written or oral exam.
Media	Slides, whiteboard.
Literature	• Gerry B. Andeen. Robot Design Handbook. McGraw-Hill, 1988. • Eugene I. Rivin. Mechanical design of robots. McGraw-Hill, 1988.

3 Module group “Specialization *Intelligent Robots*” (PIR)

Adaptive Filtering

Module group and semester	MAS, 2. Semester, Specialization “Principles of Robotics Systems Design” (PRSD)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Paul Plöger
Teacher	Prof. Dr. Paul Plöger
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	Foundations of signal / systems theory, profound mathematical, technical, physical and scientific knowledge, interest in technical application domains of embedded systems (eg consumer electronics, automotive applications, medical devices, telecommunications devices, ...) and applied mathematics
Learning targets	Professional competency: Understanding the principles of the adaptation process as such. In-depth knowledge of the methodological and theoretical foundations of systems for signal processing in time, frequency and z-domain. Individual competency: Ability to study and understand in-depth specializations like adaptive vision, sound and speech processing.
Content	Work-out and deepening of deterministic and random signals in linear, time-invariant systems. Study the foundations and applications of adaptive filters and adaptive prediction. Treatment of selected non-linear and multi-dimensional systems and deepening the knowledge in convergence of iterative solution methods.
Passing requirements	Solutions to Exercises and successful completion of the placement tests, written final examination
Expected study efforts	Active participation in lectures, solution of homework exercises. 50% submissions are required and 50% of the points have to be reached. There will be drill, advanced and programming exercises.
Media	Lecture using predominantly visual media, on the blackboard, exercises, interactive learning platform (MOODLE or Ilias), educational articles, and technical writings like application notes, experiments on real HW.
Literature	• B. Widrow, S. D. Stearns, Adaptive Signal Processing, Pearson Education, ISBN 9788131705322, 2nd printing 2009;

	• B. Farhang-Boroujeny, Adaptive filters, Wiley, ISBN 978-0-471-98337-8, 2006. • B.D.O. Anderson, J.B. Moore, Optimal Filtering, Dover Books on Engineering • Oppenheim, Schaefer: Discrete Time Signal Processing, Prentice Hall

Learning and Adaptivity

Module group and semester	MAS, 2. Semester, Specialization “Principles of Intelligent Robotics” (PIR)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Gerhard Kraetzschmar
Teacher	Prof. Dr. Gerhard Kraetzschmar
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	Familiarity with basic concepts of information theory, computational complexity, and probability theory.
Learning targets	Professional competency: Students know the benefits and pitfalls, as well as prerequisites and limitations of contemporary learning approaches and their associated methods and techniques. They have practical experience in designing and implementing self-learning systems. Methodological competency: Ability to apply concepts, methods, and tools that enable learning and adaptivity to various robotic tasks. Ability to analyze and prepare data sets for learning tasks. Individual competency: Improved skills for data visualization, including in high-dimensional spaces. Ability to understand, discuss and reason about such spaces and visualizations.
Content	– Learning Architectures and Learning Problems – General Concepts in Machine Learning – Version Space Learning – Decision Tree Learning – Inductive Logic Programming – Neural Networks: Biological Foundations – Artificial Neural Network Learning – Competitive Learning – Reinforcement Learning – Genetic Algorithms
Passing requirements	Homeworks and Examination
Expected study efforts	Active participation in class. Solution of homework exercises. Performing and documenting learning experiments. Written or oral examination.

Media	Slides, whiteboard, online demonstrations. Moodle supported.
Literature	Textbook: • Alpaydin: Introduction to Machine Learning. MIT Press, 2004. Supplementary: • Mitchell: Machine Learning. McGraw Hill, 1997. • Haykin: Neural Networks. 2nd ed. Prentice-Hall, 1998. • Sutton & Barto: Reinforcement Learning. MIT Press, 1998. • Russell & Norvig: Artificial Intelligence – A Modern Approach, 2nd edition. Prentice Hall, 2002. • Weiss: Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence. MIT Press, 1999.

Multi-Agent Systems

Module group and semester	MAS, 2. Semester, “Principles of Intelligent Robotics” (PIR)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Gerhard Kraetzschmar
Teacher	Prof. Dr. Gerhard Kraetzschmar
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	Sound knowledge of logics and basic AI concepts.
Learning targets	Professional competency: Knowing and understanding basic concepts and architectures of multiagent systems. Methodological competency: The students can apply concepts and architectures for multiagent-based and distributed artificial intelligence-based systems in practice. Individual competency: Strengthened ability to think about, conceive, and construct distributed and concurrent systems and to understnd their dynamic and emergent properties.
Content	• Intelligent autonomous agents • Logical foundations of multiagent systems • Agent architectures development frameworks • Agent communication and coordination • Agent competition and cooperation • Multiagent decision making • Markets and multiagent systems • Auctions and mechanism design
Passing requirements	Exam
Expected study efforts	Active participation in class. Solution of homework exercises. Successful solution of a term project. Examination.
Media	Slides, witeboard, online demonstrations, moodle supported.

Literature	• Michael Wooldridge: An Introduction to Multiagent Systems, Wiley, 2009 • Mark d'Inverno, Michael Luck: Understanding Agent Systems, Springer, 2010 • Yoav Shoham, Kevin Leyton-Brown: Multiagent Systems: Algorithmic, Game-Theoretic, and Logical Foundations, Cambridge University Press, 2008

Probabilistic Methods for Robotics

Module group and semester	MAS, 2. Semester, Specialization “Principles of Intelligent Robotics” (PIR)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Prassler
Teacher	Prof. Dr. Prassler
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	Familiarity with basic concepts of theory of computation and complexity theory, basic knowledge of probability theory, linear algebra and differential equations.
Learning targets	Professional competency: The students know probabilistic models like Bayesian Networks, Gaussian and other probability distributions to describe uncertain processes. Methodological competency: Ability to apply probabilistic methods like Kalman Filters or Particle Filters to data processing, modeling and reasoning tasks. Individual competency: Sensibility for strength and limits of the significance and validity of probabilistic descriptions and probability based arguments.
Content	• Probability theory and uncertainty • Probabilistic reasoning and bayesian networks • Probabilistic reasoning over time • Dynamic Bayesian Networks • Making simple decisions • Making complex decisions
Passing requirements	Homework and Examination
Expected study efforts	Active participation in class. Solution of homework exercises. Oral or written examination.
Media	Slides, whiteboard.
Literature	Thurn & Burgard & Fox: Probabilistic Robotics. MIT Press, 2005.

Robot Perception

Module group and semester	MAS, 2. Semester, Specialization “Principles of Intelligent Robotics” (PIR)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Paul Plöger
Teacher	Prof. Dr. Paul Plöger
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	profound mathematical, physical and especially geometric knowledge
Learning targets	Professional competency: The students know the foundations of image geometry, have a deep understanding of the methodological and theoretical aspects of 3D sensors, 3D-vision, -mapping and -reconstruction techniques. They understad the correspondence problem and its partial solutions as well as techniques for motion capture and visual navigation. Methodological competency: Application of theories to generated real life data, parameter adaptation of theoretical algorithms to experimental data, confident application of mathematical methods. Individual competency: Build up problem consciousness for 3D mapping, understanding solution approaches and ability to transfer the solution procedures to related problems.
Content	Rigid body transformations, Image Formation, Image Primitives and Correspondence, Reconstruction from two calibrated Views, Estimation of Motions from two views.
Passing requirements	Exam
Expected study efforts	Active participation in lectures, solution of homework exercises. 50% submissions are required. 50% of the points have to be reached. There will be drill, advanced and programming exercises
Media	Lecture using predominantly visual media, on the blackboard, exercises, interactive learning platform, educational articles, and technical writings like application notes.
Literature	• Hanspeter A. Mallot und John S. Allen : Computational Vision: Information Processing in Perception and Visual Behavior (Computational Neuroscience). MIT Press, 2000

	• Desolneux et.al.: From Gestalt Theory to Image Analysis. Springer, 2008. • Yi Ma et.al.: An Invitation to 3-D Vision. Springer, 2004 • Gonzalez & Woods: Digital Image Processing. Prentice Hall, 2002

Planning and Scheduling

Module group and semester	MAS, 2. Semester, Specialization “Principles of Intelligent Robotics” (PIR)
Credits	6
Weekly hours	Lecture: 2, Lab: 2
Responsible	Prof. Dr. Gerhard Kraetzschmar
Teacher	Prof. Dr. Gerhard Kraetzschmar
Language	English
Studdy effort at univesity	60 hours
Study effort homework	120 hours
Prerequisits	Sound knowledge of data structures and algorithms, computational complexity, and concepts of logics and probability theory. Familiarity with programming languages C++ and Java.
Learning targets	Professional competency: The students know concepts, methods, and tools for task-level planning and scheduling. Methodological competency: The students know the state-of-the-art in task planning and are able to select and apply adequate methods for use in robot applications. Individual competency: Improved ability to perform abstract thinking and logical reasoning. Ability to formalize domain concepts in appropriate logics.
Content	– Knowledge representation – Formalizing action and action theories – State space planning: STRIPS and friends – Plan space planning: POP and friends – Graph-based planning – SAT-based planning – HTN planning – Scheduling and resource constraints – Temporal planning – Conditional planning, POMDPs – Multiagent planning
Passing requirements	Exam
Expected study efforts	Active participation in class. Solution of homework exercises. Successful solution of a term project. Examination.
Media	Slides, whiteboard, online demonstrations. Moodle supported.
Literature	Textbook and Survey Articles:

	• Ghallab & Nau & Traverso: Automated Planning. Morgan Kaufmann, 2004. • Russell & Norvig: Artificial Intelligence – A Modern Approach, 2nd edition. Prentice Hall, 2002. • Weld: An Introduction to Least Commitment Planning. AI magazine, 15(4), 27-61, 1994. • Weld: Recent Advances in AI Planning. AI magazine, 20(2), 93-122, 1999.

4 Module group “R&D Project” (RND)

Research and Development Project

Module group and semester	MAS, 3. Semester, R&D Project (RND)
Credits	15
Weekly hours	2
Responsible	Prof. Dr. Erwin Prassler
Teacher	Prof. Dr. Erwin Prassler Prof. Dr. Paul Plöger Prof. Dr. Gerhard Kraetzschmar Dr. Björn Kahl et al.
Language	English
Studdy effort at univesity	30 hours
Study effort homework	420 hours
Prerequisits	Core Courses, ISW
Learning targets	Professional competency: Solid understanding of the state of the art of selected research topic. Methodological competency: Solving a given limited scientific problem independently, organizing the necessary work steps (time and project management), preparing a state of the art, identifying short comings and possible enhancements. Individual competency: Proposing a solution to an open scientific problem. Arguing scientifically in written form for the proposed solution, describing its main ideas, relation to previous work and its limits.
Content	Performing research and technological development in a limited context in the field of autonomous systems. Activities include creating a literature survey, identifying open questions or short-comings of existing approaches, proposing enhancements to known solutions, implementing proof-of-concept solutions. Previous list is neither exclusive nor are all activities necessarily present in a given R&D project. The project will be closely guided by typically two advisors, at least one of which is a MAS professor.
Passing requirements	Project report.
Expected study efforts	Combined oral exam with RDC
Media	n/a

Literature	Will be individually assigned, based on selected project topic.

Research and Development Colloquium

Module group and semester	MAS, 3. Semester, R&D Project (RND)
Credits	3
Weekly hours	2
Responsible	Prof. Dr. Erwin Prassler
Teacher	Prof. Dr. Paul Plöger Prof. Dr. Erwin Prassler Prof. Dr. Gerhard Kraetzschmar Dr. Björn Kahl et al.
Language	English
Studdy effort at univesity	30 hours
Study effort homework	60 hours
Prerequisits	RDP
Learning targets	Professional competency: Different presentation and publication forms of scientific results. Methodological competency: Preparing written and oral presentations of own scientific results. Writing and revising scientific papers for conference or journal publications. Individual competency: Presenting own scientific results to a wider auditorium, both in written form and as oral presentation.
Content	n/a
Passing requirements	Oral Exam
Expected study efforts	Public presentation and (non-public) questioning.
Media	n/a
Literature	n/a

5 Module group "Master-Thesis" (MTHES)

Master Thesis Project

Module group and semester	MAS, 4. Semester,Master-Thesis (MTHES)
Credits	24
Weekly hours	2
Responsible	Prof. Dr. Paul Plöger
Teacher	Prof. Dr. Erwin Prassler Prof. Dr. Gerhard Kraetzschmar Prof. Dr. Paul Plöger et.al.
Language	English
Studdy effort at univesity	30 hours
Study effort homework	690 hours
Prerequisits	RDP and RDC, all mandatory course work finished
Learning targets	Professional competency: Advance understanding of the state of the art of selected research topic and its limits. Methodological competency: Identifying a limited open scientific problem, analyzing the relevant state of the art and its short comings. Devising a work hypotheses for overcoming the problem. Organizing the necessary work steps (time and project management) to investigate the problem and its proposed solution and. Design and conduct necessary experiments. Report in writing about the scientific findings, its advantages and limits. Individual competency: Discovering limits and loop holes of scientific results. Proposing a solution to an identified scientific problem. Arguing scientifically orally and in and written form for own scientific findings, describing its main ideas, relation to previous work and its limits.
Content	Performing research and technological development in a limited context in the field of autonomous systems, advancing the state of the art. Activities include creating a literature survey, identifying open questions or short-comings of existing approaches, proposing enhancements to known solutions, implementing proof-of-concept solutions. Previous list is neither exclusive nor are all activities necessarily present in a given Master Thesis Project. Typically the Master Thesis Project is a continuation of an R&D project, but more focused on scientific presentations and in-depth theoretical as well as experimental analysis and comparison of the proposed approach to the published state of the art.

Passing requirements	Project report.
Expected study efforts	Combined oral exam with MC.
Media	n/a
Literature	n/a

Master Colloquium

Module group and semester	MAS, 4. Semester,Master-Thesis (MTHES)
Credits	3
Weekly hours	2
Responsible	Prof. Dr. Paul Plöger
Teacher	Prof. Dr. Erwin Prassler Prof. Dr. Gerhard Kraetzschmar Prof. Dr. Paul Plöger et.al.
Language	English
Studdy effort at univesity	30 hours
Study effort homework	60 hours
Prerequisits	RDP, RDC and MTP, all mandatory course work finished
Learning targets	Professional competency: Different presentation and publication forms of scientific results. Methodological competency: Preparing written and oral presentations of own scientific results. Writing and revising scientific papers for conference or journal publications. Individual competency: Presenting own scientific results to a wider auditorium, both in written form and as oral presentation. Publishing scientific results to a conference or journal.
Content	n/a
Passing requirements	Oral Exam
Expected study efforts	Public presentation and (non-public) questioning.
Media	n/a
Literature	n/a

6 Module group “Seminars” (SEM)

Introduction to Scientific Working

Module group and semester	MAS, 1. Semester, Seminars (SEM)
Credits	6
Weekly hours	2
Responsible	Prof. Dr. Erwin Prassler
Teacher	Prof. Dr. Erwin Prassler
Language	English
Studdy effort at univesity	30 hours
Study effort homework	150 hours
Prerequisits	Curiosity, systematic thinking, endurance, willingness to work hard.
Learning targets	Professional competency: Performing a literature survey. Knowing criteria to distinguish good from weak research papers. Proficiency in using scientific literature databases and using tools for literature and idea management. Methodological competency: Systematically approach a new (scientific) subject, identify the state of the art in a certain field. Distinguish what has been achieved and where the hard problems and open issues are. Concisely defining the direction of own research. Individual competency: Doing first steps towards ones own research.
Content	In group work we will address the following issues and questions: • What are helpful resources for literature search? • What is a citation index and how to use it? • How to systematically search papers? • How to create a key word structure and identify related topics? • How to create "your own" citation index? • How to sort and classify all the literature which you found? • How to create a bibliography and what styles to use? • How to create an annotated bibliography? • How to read and analyze scientific articles?

	• What is a good paper and what is a bad one?
Passing requirements	Leistungsnachweis
Expected study efforts	Annotated, sorted and structured bibliography covering the 30 most relevant papers for a give subject.
Media	Whiteboard, Slides, Handouts
Literature	Prassler E. (2005). *How to do a systematic literature survey - some basic techniques.* Lawrence, S. C. L. Giles, K. Bollacker. (1999). Digital Libraries and Autonomous Citation Indexing. *IEEE Computer, Volume 32, Number 6, pp. 67-71.* http://citeseer.ist.psu.edu/aci-computer/aci-computer99.html. Wes Huang (2001). *How to read a research paper.* Rensselaer Polytechnic Institute. Mike Ashby (2000). *How to write a paper.* Univ. of Cambridge, UK. http://www-2.cs.cmu.edu/afs/cs.cmu.edu/user/mleone/web/how-to.html (accessed: 2011-07-10)

Advanced Scientific Working

Module group and semester	MAS, 2. Semester, Seminars (SEM)
Credits	6
Weekly hours	2
Responsible	Prof. Dr. Erwin Prassler
Teacher	Prof. Dr. Erwin Prassler
Language	English
Studdy effort at univesity	30 hours
Study effort homework	150 hours
Prerequisits	curiosity, systematic thinking, endurance, module ISW
Learning targets	Professional competency: Knowing structure and style of different kinds of scientific writings. Citation styles and proper handling of references and third party contributions. Methodological competency: To identify the state of the art in a certain field and the major achievements and contributions. Ability to analyze and evaluate a scientific paper and its scientific contributions and deficits. Identifying the scientific challenges and problems in a field, generating a problem formulation for ones own research. Individual competency: Ability to work on a scientific subject and to conduct independent research beyond the state of the art.
Content	In group work we will address issues such as: • how to read and evaluate a paper • how to analyze and present the scientific content of a paper • how to compare several scientific approaches • how to identify the 30 most relevant article in a selected field • how to sort and classify this articles • how to write a state-of-the-art report • how to write a survey article on a selected field, and • how to derive from the state of the a problem formulation of own research

Passing requirements	Leistungsnachweis
Expected study efforts	• Six essays analyzing the contributions and deficits of six selected scientific papers. • Annotated bibliography for R&D project. • Problem formulation for R&D project. • Extended abstract.
Media	Wiki and Whiteboard
Literature	George D. Gopen and Judith A. Swan. The Science of Scientific Writing. *American Scientist*, Volume 78, 550-558, 1990.

7 Module group “Lab Courses” (LAB)

Scientific Experimentation and Evaluation

Module group and semester	MAS, 3. Semester, Lab Courses (Lab)
Credits	3
Weekly hours	4
Responsible	Dr. Björn Kahl
Teacher	Dr. Björn Kahl Prof. Dr. Gerhard Kraetzschmar
Language	English
Studdy effort at univesity	60 hours
Study effort homework	30 hours
Prerequisits	BCS level understanding of mathematics und physics. Modules AMR and MRC.
Learning targets	Professional competency: Knowledge and understanding of: Different types of scientific experiments. Mathematical methods to model physical processes, mathematical models of the measurement process. Methods for statistical data analysis. Methodological competency: Formulating scientific hypotheses. Designing, conducting and documenting scientific experiments in the domain of mobile robots and autonomous systems. Careful evaluation of experimental data, assessing scientific soundness of various statistical data analysis methods in different contexts. Selecting the appropriate sensors and evaluation methods for scientific experiments. Individual competency: Systematic analysis of complex systems. Accurate empirical working and observing. Being aware of own biases and expectations. Maintaining a critical distance to own scientific findings.
Content	Based on real mobile robots (like mindstorm kits or similar educational robots) the scientific experimentation in the context of mobile robots and autonomous systems is practiced. Topics to cover are: Theoretical design and practical conduction and proper documentation of scientific experiments. What to measure and how to measure. The measurement process. Modeling measurement errors, error propagation, stochastic analysis. Identifying and eliminating unwanted side-effects. Sensors and actors used in mobile robots, their properties and limitations. Data visualization.

Passing requirements	Leistungsnachweis
Expected study efforts	Regular lab participation, solving the experimental tasks, written reports for each experiment conducted, sort oral presentations of experiments and findings.
Media	Practical lab course, work in small groups (3-5 persons), designing, setting-up and conducting experiments using robot experimentation kits like Lego mindstorm and other hardware.
Literature	Textbook: • Experimentation: An Introduction to Measurement Theory and Experiment Design. D.C. Baird 1995 (ISBN-13: 978-0133032987) Supplementary books (selection): • Design of Experiments: A Realistic Approach. Virgil L. Anderson, John Ed. Anderson, Rober A. McLean 1974 (ISBN-13: 978-0824761318) • Experimentation and Measurement. W.J. Youden 1999 (ISBN-13: 978-0486404516) • Statistics for Experimenters: An Introduction to Design, Data Analysis and Model Building (Wiley Series in Probability & Mathematical Statistics). George E.P. Box, William G. Hunter, J. Stuart Hunter 1978 (ISBN-13: 978-0471093152)

Software Development Project

Module group and semester	MAS, 2. Semester, Lab Courses (Lab)
Credits	6
Weekly hours	6
Responsible	Prof. Dr. Gerhard Kraetzschmar
Teacher	Prof. Dr. Gerhard Kraetzschmar Dr. Björn Kahl et al.
Language	English
Studdy effort at univesity	90 hours
Study effort homework	90 hours
Prerequisits	C++ and Java programming experience
Learning targets	Professional competency: Knowing modern software engineering methods: Description languages to model data, process or control flow aspects of software systems. Understanding specific challenges of distributed or multi-threaded architectures. Knowing standard algorithms and data structures for data management (lists, trees, sets etc.) Understanding usability and accessibility constraints. Methodological competency: Creating and assessing software designs for given application problems. Analyzing failure modes and error conditions for software systems. Concise specification of requirements of software systems. Maintaining complete and accurate software documentation (user documentation as well as implementation documentation). Individual competency: Structuring complex (software) problems into its constituents. Organizing and conducting collaborative work in a team. Creating detailed specifications from vague problem descriptions.
Content	Agile software team techniques are studied and practiced in the context of developing software for robotics and embedded systems. – object-oriented software design – agile software development, extreme programming – model-driven software development – software patterns – refactoring In addition, students will deepen their practical skills with state-of-the-art software development tools (e.g. Eclipse, Subversion, Git, Hudson).

Passing requirements	Project work and Examination
Expected study efforts	Active participation in class. Successful formation of and participation in student teams. Solving project assignments at home and in theory and practice sessions. Examination.
Media	Slides, whiteboard, online demonstrations. Moodle supported. Project repository.
Literature	Textbook: – Martin: Agile Software Development: Principles, Patterns, and Practices. Prentice Hall/Pearson Education, 2003. – McConnell: Code Complete 2 Supplementary: – Summerville: Software Engineering, 7th edition. Addison Wesley, 2004. – Gamma, Helm, Johnson, Vlissides: Design Patterns, Addison Wesley, 2005 – Zeller: Why Programs Fail: A Guide to Systematic Debugging, 2nd edition, Morgan Kaufmann 2009