Technische Hochschule Ingolstadt

Module Handbook
MEng. AI Engineering of Autonomous Systems

Faculty of Electrical Engineering and Computer Science

As per: 2024-09-27

Content

1 Introduction and Overview

The rise of AI and autonomous systems is about to revolutionise various industries and find application in a wide range of fields, from transportation and logistics to healthcare and agriculture. Self-driving cars are transforming the automotive industry, promising safer and more efficient transportation. Unmanned aerial vehicles (UAVs) are revolutionising delivery services, enabling quick and reliable parcel distribution. In industries like manufacturing and warehousing, autonomous robots streamline operations, enhancing productivity and reducing costs. As the demand for AI engineers and experts continues to soar, this Master's programme aims to nurture a new generation of professionals who can harness the power of AI to create innovative and intelligent autonomous systems.

Throughout this program, students will learn how to design, develop, and deploy intelligent systems that can learn, make decisions and operate autonomously, i.e., without human intervention. Basic building blocks of autonomous systems such as sensor networks and data fusion, data engineering, computing as well as communication technologies are explored and combined with AI engineering methods like perception and cognition, machine learning and decision making.

2 Programme Description

2.1 Contents

The programme consists of compulsory modules in the following areas:

- Intelligent Perception and Exploration

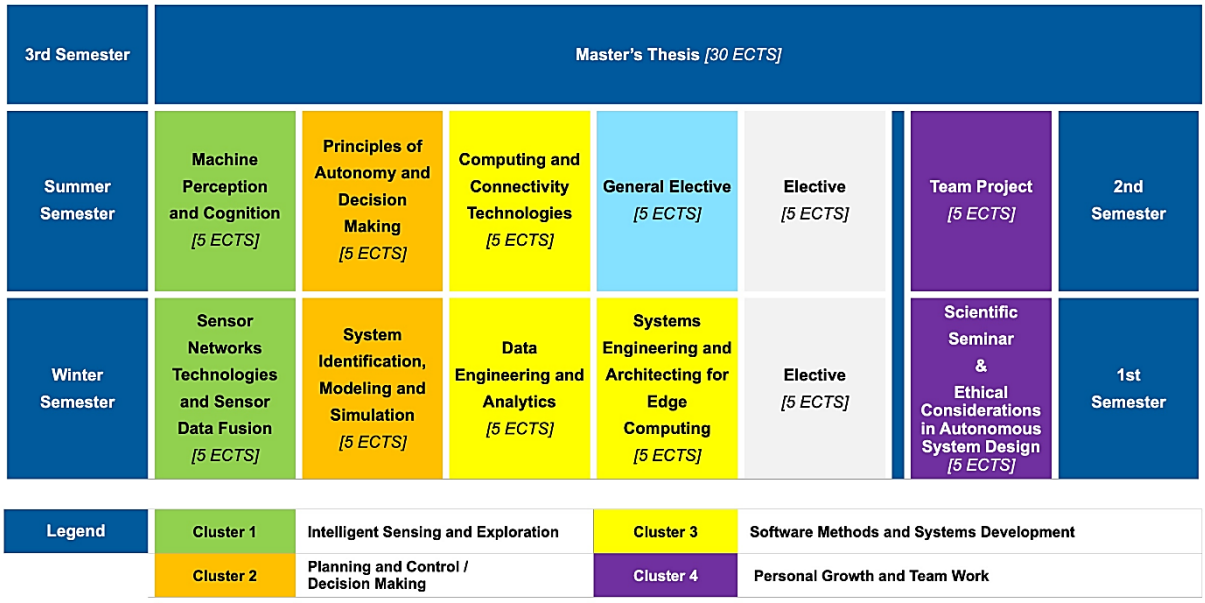
  Sensors are the sensory organs of autonomous systems, key to their mobility and autonomy. Data from multiple and even different sensors are combined to quickly and accurately communicate information about the environment, physical events, activities or situations to decision-making components.

- Planning, Control and Decision Making

  Planning with intelligence is a prerequisite for autonomous and predictive action. Systems need to be able to plan their actions in order to achieve a given goal and to respond to unexpected or new situations by changing their behaviour. Machine learning methods are used to combine sensor-data with past experience and draw conclusions that can be used to improve actions.

- Software Methods and System Development

  The development of autonomous systems is approached from a software engineering perspective. Various characteristics of autonomous systems, architectures, and models will be covered in order to demonstrate the technical feasibility of systems that dynamically adapt their behaviour to chang-es in operating conditions by means of software.



The compulsory part is complemented by elective modules. These modules focus on specific aspects of the development of autonomous systems, automotive applications, innovation management, or engineering processes applied in tech companies as well as German language courses.

The Scientific Seminar introduces the students to a state-of-the-art topic in AI engineering. The topic will be presented and discussed with peers as well as summarised in a seminar paper. The Team Project provides students with an experience of 'learning by doing' and collaboration in a team of their peers by solving an engineering problem using the acquired engineering skills.

2.2 Graduation

After successful completion of the Master`s Programme, the Technische Hochschule Ingolstadt awards the academic degree:

Master of Engineering (M.Eng.)

2.3 Advisor and Programme Coordinator

For all technical and functional questions and problems with regards to contents of the Master‘s programme please contact:

Prof. Dr.-Ing. Michael Mecking

For questions concerning the organizational execution of the study programme please contact:

Prof. Dr.-Ing. Michael Mecking

The office hours during the semester will be announced via Moodle.

3 Curricular structure

The Master's degree course starts every summer and winter semester. Due to the modular structure of the course, it is possible to complete all subjects both at the beginning of the summer semester and at the beginning of the winter semester. Therefore, not every subject is offered in every semester. The following two tables show the respective curriculum for a winter semester or summer semester start.

The modules are taught in presence at the Technische Hochschule Ingolstadt (THI).

3.1 General compulsory subjects

Start of studies in the winter semester

SPO -No.	Module	1. Semester			2. Semester			3. Semester	
		SWS	ECTS	Exam	SWS	ECTS	Exam	SWS	ECTS
1	Machine Perception and Cognition				4	5	WE		
2	System Identification, Modeling and Simulation	4	5	WE					
3	Data Engineering and Analytics	4	5	WE					
4	Scientific Seminar	2	2.5	SA					
5	Ethical Considerations in Autonomous System Design	2	2.5	OE					
6	Sensor Networks Technologies and Sensor Data Fusion	4	5	WE					
7	Principles of Autonomy and Decision Making				4	5	PE		
8	Computing and Connectivity Technologies				4	5	OE		
9	Systems Engineering and Architecting for Edge Computing	4	5	WP					
10	Team Project				4	5	Proj		
11	General Elective				4	5	LN		
12	Science Elective	4	5	LN	4	5	LN		
13	Master Thesis (incl. Colloqium)							0	30
	Sum	**24**	**30**		**22**	**30**		**0**	**30**

Start of studies in the summer semester

SPO -No.	Module	1. Semester			2. Semester			3. Semester	
		SWS	ECTS	Exam	SWS	ECTS	Exam	SWS	ECTS
1	Machine Perception and Cognition	4	5	WE					
2	System Identification, Modeling and Simulation				4	5	WE		
3	Data Engineering and Analytics				4	5	WE		
4	Scientific Seminar				2	2.5	SA		
5	Ethical Considerations in Autonomous System Design				2	2.5	OE		
6	Sensor Networks Technologies and Sensor Data Fusion				4	5	WE		
7	Principles of Autonomy and Decision Making	4	5	PE					
8	Computing and Connectivity Technologies	4	5	OE					
9	Systems Engineering and Architecting for Edge Computing				4	5	WP		
10	Team Project	4	5	Proj					
11	General Elective	4	5	LN					
12	Science Elective	4	5	LN	4	5	LN		
13	Master Thesis (incl. Colloqium)							0	30
	Sum	**24**	**30**		**22**	**30**		**0**	**30**

WE	Written Exam
OE	Oral Exam
PE	Practical Exam
SA	Seminar Presentation and Paper
Proj	Project Work, Presentation and Paper
MA	Master's Thesis, written form
CO	Colloqium
LN	Written, Oral or Practical Exam

4 Description of Modules

4.1 Compulsary modules

Machine Perception and Cognition			
Module abbreviation:	AI_MachPerception	**Reg.no.:**	1
Curriculum:	**Programme**	**Module type**	**Semester**
	AI Engineering of Autonomous Systems (SPO WS 23/24)	Compulsory Subject	1
Module frequency:	only summer term	**Duration:**	1 semester
Responsible for module:	Hagerer, Andreas		
Lecturer:	Hagerer, Andreas; Passig, Georg		
Language of instruction:	English	**Language of exam:**	English
Credit points / SWS:	5 ECTS / 4 SWS		
Workload:	Contact hours: 47 h Self-study: 78 h Total: 125 h		
Subjects of the module:	1: Machine Perception and Cognition		
Lecture types:	SU/Ü - lecture with integrated exercises		
Availability of the module:	This module is not a compulsory module in any other degree programme of the faculty. When changing to a degree programme of another faculty, the possibilities for credit transfer must be discussed with the responsible persons.		
Examinations:			
schrP90 - written exam, 90 minutes			
Further explanations regarding examinations:			
None			
Prerequisites according examination regulation:			
None			
Recommended prerequisites:			
knowledge in linear algebra and logic, graph representations			
Objectives:			
After successfully completing this module, the students shall be able to • understand and analyse image formation in a camera and name the main factors influencing image quality, image sharpness, brightness, resolution and frame rate • understand the basics of audio signal processing, feature analysis and audio recognition • state the basics of digital and analogue camera technology and corresponding transmission methods • apply and recognise linear and non-linear filters and convolution operations appropriately • extract features (corners, edges and contours) from images, apply threshold operations and determine the properties of regions, edges and contours • apply classical and modern machine learning and deep learning algorithms to automate computer vision tasks • explain the basics of object recognition and image search, object detection techniques			

- explain the theoretical background of convolutional neural networks and their application for object recognition
- acquire an overall understanding of the data flow and data quality from signal generation to cognition, independent of the actual field of application

Content:

Topics will be chosen from contemporary areas of deep machine learning applied to tasks within the context of machine perception and cognition including the following:

1. Machine perception
   - signal flow from physical signals to electrical signals, sampling, discretization, Nyquist-Shannon-theorem to feature extraction. Examples from electrical engineering, audio analysis and image recognition
   - linear and nonlinear filters
   - one- and two-dimensional fast Fourier-transformation
   - convolution in one- and two-dimensional data, concept and application
   - region morphology
   - classification methods (hypercubes/spheres, SVM, KNN)
2. Machine cognition
   - foundation of machine cognition
   - discriminative methods of object classification: naive Bayes, neural networks, CNNs
   - implementation of discriminant methods in Python
   - graphical models: Bayes nets, Markov networks
   - semantic segmentation
   - object detection: part based models, region based models

Literature:

- SZELISKI, Richard, 2022. *Computer Vision: Algorithms and Applications* [online]. Cham: Springer International Publishing PDF e-Book. ISBN 978-3-030-34372-9. Available via: https://doi.org/10.1007/978-3-030-34372-9.
- DICKMANNS, Ernst Dieter, 2007. *Dynamic vision for perception and control of motion* [online]. London: Springer PDF e-Book. ISBN 978-1-84628-637-7, 978-1-84628-638-4. Available via: https://doi.org/10.1007/978-1-84628-638-4.
- KORB, Kevin B., NICHOLSON, Ann E., 2011. *Bayesian artificial intelligence* [online]. Boca Raton: CRC Press PDF e-Book. ISBN 978-0-429-07539-1, 978-1-4398-1592-2. Available via: https://doi.org/10.1201/b10391.
- IOSIFIDIS, Alexandros, TEFAS, Anastasios, 2022. *Deep learning for robot perception and cognition* [online]. London, United Kingdom ; San Diego, CA, United States ; Cambridge, MA, United States ; Kidlington, Oxford, United Kingdom: Academic Press PDF e-Book. ISBN 978-0-323-88572-0, 978-0-323-85787-1. Available via: https://doi.org/10.1016/C2020-0-02902-6.

Additional remarks:

None

System Identification, Modeling and Simulation

Module abbreviation:	AI_SysIdent	**Reg.no.:**	2
Curriculum:	**Programme**	**Module type**	**Semester**
	AI Engineering of Autonomous Systems (SPO WS 23/24)	Compulsory Subject	1
Module frequency:	only winter term	**Duration:**	1 semester
Responsible for module:	Ebert, Bernd Martin		
Lecturer:	Ebert, Bernd Martin		
Language of instruction:	English	**Language of exam:**	English
Credit points / SWS:	5 ECTS / 4 SWS		
Workload:	Contact hours: 47 h Self-study: 78 h Total: 125 h		
Subjects of the module:	2: System Identification, Modeling and Simulation		
Lecture types:	SU/Ü - lecture with integrated exercises		
Availability of the module:	This module is not a compulsory module in any other degree programme of the faculty. When changing to a degree programme of another faculty, the possibilities for credit transfer must be discussed with the responsible persons.		

Examinations:

schrP90 - written exam, 90 minutes

Further explanations regarding examinations:

None

Prerequisites according examination regulation:

None

Recommended prerequisites:

Engineering mathematics
Basics of physics: kinematics, mechanics, electricity
Relationships between describing variables (force, torque, current, ...) of the mechanical and electrical energy domain
Basics of programming
Basics of control engineering

Objectives:

After successfully completing the module, students shall be able to:

- understand the process of system modelling
- formulate mathematical models of physical systems by means of input/output equations
- model systems of different energy domains in state space as well as transfer function representation according to unified approaches
- implement the mathematical model using software tools (e.g. Matlab/Simulink)
- analyze, validate and interpret the simulation results
- assess and design a controller for a given plant

Content:

The following topics are covered:

- Modelling of complex mechanical, electrical, thermo-fluidic and interconnected systems
- Linearity: scaling, superposition, linearization of nonlinear processes
- Lagrange formalism of second type to derive equations of motion
- Laplace transforms, transfer functions, and frequency response analysis, behaviour (forced/unforced time and frequency domain responses) of linear time-invariant (LTI) ordinary differential equations.
- Numerical integration and computer simulation.
- Design and implementation of controllers
- Adaptive control by reinforcement learning
- Tools: Solution of dynamic problems using a digital simulation packages for continuous time/sampled data systems such as MATLAB and Simulink

Literature:

- ESHKABILOV, Sulaymon L., 2020. *Practical MATLAB modeling with Simulink: programming and simulating ordinary and partial differential equations* [online]. Berkeley, CA: Apress PDF e-Book. ISBN 978-1-4842-5799-9. Available via: https://doi.org/10.1007/978-1-4842-5799-9.
- BROWN, Forbes T., 2007. *Engineering system dynamics: a unified graph-centered approach*. 2. edition. Boca Raton, FL [u.a.]: CRC, Taylor & Francis. ISBN 978-0-8493-9648-9, 0-8493-9648-4
- KARNOPP, Dean, Donald L. MARGOLIS and Ronald C. ROSENBERG, 2012. *System dynamics: modeling, simulation, and control of mechatronic systems*. 5. edition. Hoboken: Wiley. ISBN 978-1-118-15982-8
- PALM III, William John, 2021. *System dynamics* . 4. edition. New York, NY: McGraw-Hill. ISBN 978-1-260-57076-2
- BERTSEKAS, Dimitri P., 2019. *Reinforcement learning and optimal control*. Belmont, Massachusetts: Athena Scientific. ISBN 978-1-886529-39-7

Additional remarks:

None

Data Engineering and Analytics

Module abbreviation:	AI_DataEng	**Reg.no.:**	3
Curriculum:	**Programme**	**Module type**	**Semester**
	AI Engineering of Autonomous Systems (SPO WS 23/24)	Compulsory Subject	1
Module frequency:	only winter term	**Duration:**	1 semester
Responsible for module:	Schmidtner, Stefanie		
Lecturer:	Schmidtner, Stefanie		
Language of instruction:	English	**Language of exam:**	English
Credit points / SWS:	5 ECTS / 4 SWS		
Workload:	Contact hours: 47 h Self-study: 78 h Total: 125 h		
Subjects of the module:	3: Data Engineering and Analytics		
Lecture types:	SU/Ü - lecture with integrated exercises		
Availability of the module:	This module is not a compulsory module in any other degree programme of the faculty. When changing to a degree programme of another faculty, the possibilities for credit transfer must be discussed with the responsible persons.		

Examinations:

schrP90 - written exam, 90 minutes

Further explanations regarding examinations:

None

Prerequisites according examination regulation:

None

Recommended prerequisites:

Probability and Statistics, Concept of Random Variables; Linear Algebra; Analysis

Objectives:

Data analytics and data engineering are fundamental fields for the development of automated systems. The aim of the lecture is to give students a sound understanding of data analytics methods and to convey fundamentals in data engineering.

After finishing this course including exercises students are able to

- choose and calculate appropriate metrics and visualizations for describing a data set
- understand and master fundamental data analysis and machine learning methods
- have deep knowledge about model assessment and inference techniques for linear and non-linear models
- know fundamentals of data engineering

Content:

- Data visualization
- Data cleaning and data quality

- Fundamentals of statistical learning and machine learning
- Linear Regression
- Classification
- Model assessment, selection and inference: Cross-Validation & Bootstrap
- Decision Trees
- Unsupervised Learning
- Neural networks (ANN, ResNet, CNN)
- Fundamentals of data engineering (data modeling, data warehouse, data lake, parallel and distributed computing, data pipelines)

Literature:

- WILKE, Claus, March 2019. *Fundamentals of data visualization: a primer on making informative and compelling figures*. 1. edition. Beijing: O'Reilly. ISBN 978-1-492-03108-6
- JAMES, Gareth, WITTEN, Daniela, HASTIE, Trevor, TIBSHIRANI, Robert, TAYLOR, Jonathan, 2023. *An Introduction to Statistical Learning: with Applications in Python* [online]. Cham: Springer International Publishing PDF e-Book. ISBN 978-3-031-38747-0. Available via: https://doi.org/10.1007/978-3-031-38747-0.
- HASTIE, Trevor, TIBSHIRANI, Robert, FRIEDMAN, Jerome H., 2017. *The elements of statistical learning: data mining, inference, and prediction* [online]. New York, NY, USA: Springer PDF e-Book. ISBN 978-0-387-84858-7. Available via: https://doi.org/10.1007/978-0-387-84858-7.
- BISHOP, Christopher M., 2009. *Pattern recognition and machine learning*. 8. edition. New York [u.a.]: Springer. ISBN 0-387-31073-8, 978-1-4939-3843-8
- LESKOVEC, Jure, Anand RAJARAMAN and Jeffrey D. ULLMAN, 2020. *Mining of massive datasets*. T. edition. Cambridge: Cambridge University Press. ISBN 978-1-108-47634-8
- RYZA, Sandy and others, 2017. *Advanced analytics with Spark: patterns for learning from data at scale*. S. edition. Beijing: O'Reilly. ISBN 978-1-4919-7295-3

Additional remarks:

No remarks.

Scientific Seminar

Module abbreviation:	AI_ScienSeminar	**Reg.no.:**	4
Curriculum:	**Programme**	**Module type**	**Semester**
	AI Engineering of Autonomous Systems (SPO WS 23/24)	Compulsory Subject	1
Module frequency:	winter and summer term	**Duration:**	1 semester
Responsible for module:	Mecking, Michael		
Lecturer:	Mecking, Michael; Mohan, Adithya; Schlamp, Anna-Lena; Seidel, Christian; Vaculin, Ondrej		
Language of instruction:	English	**Language of exam:**	English
Credit points / SWS:	2.5 ECTS / 2 SWS		
Workload:	Contact hours: 24 h Self-study: 39 h Total: 63 h		
Subjects of the module:	4: Scientific Seminar		
Lecture types:	S - seminar		
Availability of the module:	This module is a compulsory module in some other degree programmes of the faculty. However, when changing to a degree programme of another faculty, the possibilities for credit transfer must be discussed with the responsible persons.		

Examinations:

Seminar paper with oral presentation (15-30 min) and written elaboration (10-15 pages)

Further explanations regarding examinations:

None

Prerequisites according examination regulation:

None

Recommended prerequisites:

None

Objectives:

After a successful completion of the module, the students

- have gained and deepened their ability to independently acquire knowledge in a technical field by means of literature research and analysis,
- are able to present this knowledge comprehensibly within the framework of an oral presentation using suitable supportive media,
- are able to follow a presentation and to critically and professionally discuss the contents with the speaker,
- have strengthened their interdisciplinary and communicative competences,
- are able to summarise the content of their presentation in the form of a brief written elaboration following scientific referencing guidelines.

Content:

The technical topic of the seminar changes from course to course. The subject is mostly embedded into an area closely related to AI Engineering of Autonomous Systems:

- The respective lecturer compiles a collection of publications from the technical literature.
- In the course of the seminar, each student is required to present a paper/topic that was assigned by either lot or choice at the beginning of the semester.
- In the preparation phase, each student must conduct an independent literature research on the topic and aggregate the results.
- The student will give an oral presentation on the topic lasting about 25 minutes followed by a discussion with peers. Participation in the discussions is contributing to the final grade.
- In addition to an oral presentation, the student is required to prepare a written paper on the topic of the presentation. This paper should summarise the main contents.

The respective instructor will communicate detailed information on deadlines and expectations regarding the presentation as well as the written elaboration at the beginning of the semester.

Literature:

- will be announced at the beginning of the semester

Additional remarks:

Attendance is compulsory in this module.

Ethical Considerations in Autonomous System Design			
Module abbreviation:	AI_Ethics	**Reg.no.:**	5
Curriculum:	**Programme**	**Module type**	**Semester**
	AI Engineering of Autonomous Systems (SPO WS 23/24)	Compulsory Subject	1
Module frequency:	winter and summer term	**Duration:**	1 semester
Responsible for module:	Uhl, Matthias		
Lecturer:	Richter, Florian		
Language of instruction:	English	**Language of exam:**	English
Credit points / SWS:	2.5 ECTS / 2 SWS		
Workload:	Contact hours: 24 h Self-study: 39 h Total: 63 h		
Subjects of the module:	5: Ethical Considerations in Autonomous System Design		
Lecture types:	SU/Ü - lecture with integrated exercises		
Availability of the module:	This module is not a compulsory module in any other degree programme of the faculty. When changing to a degree programme of another faculty, the possibilities for credit transfer must be discussed with the responsible persons.		
Examinations:			
mdlP - oral exam, 15-20 minutes			
Further explanations regarding examinations:			
None			
Prerequisites according examination regulation:			
None			
Recommended prerequisites:			
None			
Objectives:			
On successful completion of the course, students will be able to • outline the most pressing questions currently discussed in the ethics of autonomous systems • distinguish meta-ethical, normative, and empirical arguments in ethics • know the most important normative theories and are able apply them to the field of autonomous system design • apply ethical arguments to case studies from the field of autonomous systems, e.g., self-driving cars • discuss the role of empirical research for the ethics of human-machine interaction and machine ethics • transcend their own normative viewpoint by critically reflecting on it			
Content:			
The ethics of autonomous systems deals with questions of machine ethics and ethics of human-machine interaction. We will tackle both fields in the course. Machine ethics asks which morality artificial systems			

should apply. In which sense can they take ethical decisions? Who should bear the responsibility if something goes wrong? Should we ever leave ethical decisions to autonomous systems or do we always have to keep the human in the loop?

The ethics of human-machine interaction is interested in the ethical influence that the cooperation and competition with autonomous systems has on our own moral conduct. We need a profound empirical understanding about the unintentional and often subtle effects that these interactions have on us as humans. Do we still own our decisions if we merely follow the advice of a recommender system? Does the mediation of our experience through technology change the way we think about moral issues? Can we shape people's moral behaviour through the design of human-machine interfaces?

Literature:

- NYHOLM, Sven, 2022. *This is Technology Ethics: An Introduction*. 1. edition. ISBN 978-1119755579
- COECKELBERGH, Marc, 2020. *AI Ethics*. 1. edition. ISBN 978-0262538190

Additional remarks:

None

Sensor Networks Technologies and Sensor Data Fusion

Module abbreviation:	AI_SensorNetworks	**Reg.no.:**	6
Curriculum:	**Programme**	**Module type**	**Semester**
	AI Engineering of Autonomous Systems (SPO WS 23/24)	Compulsory Subject	1
Module frequency:	only winter term	**Duration:**	1 semester
Responsible for module:	Kefferpütz, Klaus		
Lecturer:	Kefferpütz, Klaus		
Language of instruction:	English	**Language of exam:**	English
Credit points / SWS:	5 ECTS / 4 SWS		
Workload:	Contact hours: 47 h Self-study: 78 h Total: 125 h		
Subjects of the module:	6: Sensor Networks Technologies and Sensor Data Fusion		
Lecture types:	SU/Ü - lecture with integrated exercises		
Availability of the module:	This module is not a compulsory module in any other degree programme of the faculty. When changing to a degree programme of another faculty, the possibilities for credit transfer must be discussed with the responsible persons.		

Examinations:

schrP90 - written exam, 90 minutes

Further explanations regarding examinations:

None

Prerequisites according examination regulation:

None

Recommended prerequisites:

(digital) signal processing, time-domain and frequency analysis

Objectives:

After successfully completing this module the students shall be able to

- understand the fundamental principles of sensor networks.
- understand communication in sensor networks.
- apply advanced linear and non-linear digital signal processing to a multitude of sensors.
- describe and model the most common sensors used in sensor fusion applications.
- implement basic algorithms for simultaneous localisation and mapping (SLAM).
- apply sensor fusion to different sensors like cameras, radar, etc..
- use AI methods like, e.g., federated learning to the field of sensor fusion and sensor networks.

Content:

The module comprises the following aspects of sensor networks and sensor data fusion:

- basics and advanced concepts of wireless sensor networks,
- hardware aspects of sensor nodes,

- routing in wireless networks,
- time synchronisation and localisation in wireless networks,
- data/signal processing in wireless sensor networks,
- need for multi-sensor data fusion,
- various approaches to data fusion,
- representations of data and data fusion architectures,
- algorithmic approaches to data fusion,
- applications of wireless sensor networks.

Literature:

- KARL, Holger and Andreas WILLIG, 2007. *Protocols and architectures for wireless sensor networks*. R. edition. Chichester [u.a.]: Wiley. ISBN 978-0-470-51923-3, 0-470-51923-1
- KOCH, Wolfgang, 2014. *Tracking and Sensor Data Fusion: Methodological Framework and Selected Applications* [online]. Heidelberg: Springer PDF e-Book. ISBN 978-3-642-39271-9, 978-1-306-20127-8. Available via: https://doi.org/10.1007/978-3-642-39271-9.

Additional remarks:

None

Principles of Autonomy and Decision Making

Module abbreviation:	AI_PrincAutonomy	**Reg.no.:**	7
Curriculum:	**Programme**	**Module type**	**Semester**
	AI Engineering of Autonomous Systems (SPO WS 23/24)	Compulsory Subject	1
Module frequency:	only summer term	**Duration:**	1 semester
Responsible for module:	Belzner, Lenz		
Lecturer:	Karpenahalli, Chidvilas; Mohan, Adithya		
Language of instruction:	English	**Language of exam:**	English
Credit points / SWS:	5 ECTS / 4 SWS		
Workload:	Contact hours: 47 h Self-study: 78 h Total: 125 h		
Subjects of the module:	7: Principles of Autonomy and Decision Making		
Lecture types:	SU/Ü/PR - seminar based teaching/Exercise course/laboratory		
Availability of the module:	This module is not a compulsory module in any other degree programme of the faculty. When changing to a degree programme of another faculty, the possibilities for credit transfer must be discussed with the responsible persons.		

Examinations:

Practical Exam

Further explanations regarding examinations:

None

Prerequisites according examination regulation:

None

Recommended prerequisites:

knowledge and experience in Python (object-oriented) programming

Objectives:

This course covers algorithmic decision making in the context of Markov decision processes and stochastic games, using statistical planning and machine learning algorithms (e.g., predictive models, imitation learning, reinforcement learning). The course also includes autonomous systems engineering, with particular emphasis on safety, verification, and testing of decision-making systems.

Content:

- probabilistic modeling
- optimization (heuristic, gradient-based)
- sequential decision making and search
- Markov decision processes
- dynamic programming
- statistical planning (bandits, stacked bandits, MCTS, cross-entropy planning)
- reinforcement learning

• multi-agent systems (games, stochastic games, MARL) • safety, testing and verification (risk, uncertainty, coevolution)
Literature:
Will be specified at the beginning
Additional remarks:
None

Computing and Connectivity Technologies

Module abbreviation:	AI_CompConn	**Reg.no.:**	8
Curriculum:	**Programme**	**Module type**	**Semester**
	AI Engineering of Autonomous Systems (SPO WS 23/24)	Compulsory Subject	1
Module frequency:	only summer term	**Duration:**	1 semester
Responsible for module:	Festag, Andreas		
Lecturer:	Festag, Andreas; Hagerer, Andreas		
Language of instruction:	English	**Language of exam:**	English
Credit points / SWS:	5 ECTS / 4 SWS		
Workload:	Contact hours: 47 h Self-study: 78 h Total: 125 h		
Subjects of the module:	8: Computing and Connectivity Technologies		
Lecture types:	SU/Ü - lecture with integrated exercises		
Availability of the module:	This module is not a compulsory module in any other degree programme of the faculty. When changing to a degree programme of another faculty, the possibilities for credit transfer must be discussed with the responsible persons.		

Examinations:

mdlP - oral exam, 15-20 minutes

Further explanations regarding examinations:

None

Prerequisites according examination regulation:

None

Recommended prerequisites:

internet / OSI layer model; digital communications

Objectives:

After successfully completing this module, the students shall be able to

- describe architecture, organisation and execution concepts of basic and advanced processing technologies (CPU, ISP, GPU, TPU, VPU, NPU) used to handle requirements of various applications of autonomous systems efficiently
- explain the execution of program elements by various processing technologies
- describe concepts of interconnection technologies for processor to memory communication and processor to processor communication
- understand demand for and potential of domain-specific architectures
- describe the requirements, use cases, architectures and communication technologies for exchanging information among autonomous systems
- understand transmission and media access methods, communication protocols of the network, transport and facilities layer as well as data security and system management and

- evaluate the advantages and disadvantages of current technological capabilities to deliver uninterrupted connectivity that is interoperable between different kind of mobile units, satellites and command centres and assess future developments

Content:

Computing Technology:

- organisation and architecture of computing systems: CPU, ISP, GPU, Multi-GPUs, distributed GPUs
- programming concepts for CPUs, ISPs and GPUs
- interconnection structures: crossbar switches, multi-stage networks, CYL, Infiniband, QPI
- domain-specific architectures

Connectivity Technology:

- Car2X use cases and system architecture
- WLAN-V2X and Cellular-V2X
- Architecture, channel structure, synchronisation, resource management, scheduling and overload control
- IP mobility support and ad hoc networking for Car2X

Literature:

- KUROSE, James F. and Keith W. ROSS, 2022. *Computer networking: a top-down approach*. E. edition. Harlow, United Kingdom: Pearson. ISBN 978-1-292-40546-9, 1-292-40546-5
- GEETHA, T V, SENDHILKUMAR, S, 2023. *Machine Learning: concepts, techniques and applications* [online]. Boca Raton, London, New York: CRC Press, Taylor & Francis Group PDF e-Book. ISBN 978-1-003-29010-0. Available via: https://doi.org/10.1201/9781003290100.
- WILT, Nicholas, 2013. *The CUDA handbook: a comprehensive guide to GPU programming*. 1. edition. Upper Saddle River, NJ ; Munich [u.a.]: Addison-Wesley. ISBN 978-0-321-80946-9, 0-321-80946-7
- TROPPENS, Ulf, 2009. *Storage networks explained: basics and application of Fibre Channel SAN, NAS, iSCSI, InfiniBand, and FCoE*. 2. edition. Hoboken, NJ: John Wiley. ISBN 978-0-470-74143-6
- CHAKRAVARTHI, Veena S., KOTESHWAR, Shivananda R., 2023. *System on Chip (SOC) Architecture: A Practical Approach* [online]. Cham: Springer Nature Switzerland PDF e-Book. ISBN 978-3-031-36242-2. Available via: https://doi.org/10.1007/978-3-031-36242-2.

Additional remarks:

None

Systems Engineering and Architecting for Edge Computing			
Module abbreviation:	AI_SystemsEng	**Reg.no.:**	9
Curriculum:	**Programme**	**Module type**	**Semester**
	AI Engineering of Autonomous Systems (SPO WS 23/24)	Compulsory Subject	1
Module frequency:	only winter term	**Duration:**	1 semester
Responsible for module:	Membarth, Richard		
Lecturer:	Membarth, Richard		
Language of instruction:	English	**Language of exam:**	English
Credit points / SWS:	5 ECTS / 4 SWS		
Workload:	Contact hours: 47 h Self-study: 78 h Total: 125 h		
Subjects of the module:	9: Systems Engineering and Architecting for Edge Computing		
Lecture types:	SU/Ü/PR - seminar based teaching/Exercise course/laboratory		
Availability of the module:	This module is not a compulsory module in any other degree programme of the faculty. When changing to a degree programme of another faculty, the possibilities for credit transfer must be discussed with the responsible persons.		

Examinations:

schrP90 - written exam, 90 minutes

Further explanations regarding examinations:

None

Prerequisites according examination regulation:

None

Recommended prerequisites:

Computer Architecture
C/C++ Programming
Graph Theory

Objectives:

After successful participation in the module courses, students are able to

- understand the characteristics of embedded architectures,
- identify optimization potential for algorithms to meet resource constraints,
- realize algorithms on embedded systems,
- optimize deep learning networks for execution on edge devices,
- evaluate the effect of programming alternatives on the execution speed,
- explain concepts for performance enhancement in embedded systems and the problems associated with them.

Content:

- embedded architectures

- energy efficiency
- resource constraints and scheduling
- programming for embedded architectures
- deep learning on edge devices
  - algorithms for CNNs
  - network quantization
- domain-specific architectures
  - Google TPU
  - NVIDIA Jetson

Literature:

- PATTERSON, David A. and John L. HENNESSY, 2020. *Computer Organization and Design: The Hardware Software Interface*. R. edition. Cambridge, MA, USA: Morgan Kaufmann. ISBN 978-0-12-820331-6
- GOODFELLOW, Ian, Yoshua BENGIO and Aaron COURVILLE, 2016. *Deep Learning*. ISBN 978-0-262-03561-3

Additional remarks:

Bonus points can be earned in this module by completing a programming assignment during the semester. Up to 10% of the points achievable in the examination can be additionally acquired for the programming task. Participation in the bonus system is voluntary. Bonus points will be awarded for:

- a correct, working implementation that passes the tests,
- resource aspects of the implementation (memory usage),
- performance aspects of the implementation (wall runtime).

Further details will be provided during the lecture. A clear git development history and documentation of the code development are mandatory for bonus points to be awarded. The programming assignment must undoubtedly be completed independently.

Team Project			
Module abbreviation:	AI_Project	**Reg.no.:**	10
Curriculum:	**Programme**	**Module type**	**Semester**
	AI Engineering of Autonomous Systems (SPO WS 23/24)	Compulsory Subject	2
Module frequency:	winter and summer term	**Duration:**	1 semester
Responsible for module:	Mecking, Michael		
Lecturer:	Chandra Sekaran, Karthikeyan; De Borba, Thiago; Fröhling, Felix; Geisler, Markus; Kalyana Sundaram, Abinav; Mohan, Adithya; Neumeier, Marion; Palanisamy, Saravanan; Schiendorfer, Alexander; Steffel, Pauline; Ulreich, Fabian; Wachtel Granado, Diogo		
Language of instruction:	English	**Language of exam:**	English
Credit points / SWS:	5 ECTS / 4 SWS		
Workload:	Contact hours: 47 h Self-study: 78 h Total: 125 h		
Subjects of the module:	10: Team Project		
Lecture types:	Prj - project		
Availability of the module:	This module is a compulsory module in some other degree programmes of the faculty. However, when changing to a degree programme of another faculty, the possibilities for credit transfer must be discussed with the responsible persons.		

Examinations:

Proj - Project work (5-25 pages) with oral presentation (15 minutes)

Further explanations regarding examinations:

The team project is a group work in which several students work on a common task. Each student has to contribute individually to the task, submit a project report and present the results orally.

According to the APO, the scope of the project report is 1500 words to 7500 words or approx. 5 to 25 pages, the scope of the oral presentation is 15 to 45 minutes according to the APO.

The project report is to be written with a word processing programme.

Prerequisites according examination regulation:

None

Recommended prerequisites:

Successful participation in Scientific Seminar

Objectives:

After successfully completing this module the students shall be able to

- analyse a complex technical task and partition the task into several succesive or parallel work packages,
- successfully participate, collaborate in and organise a team over the period of a whole semester,
- discuss the project progress in varying but always appropriate detail, report in oral and/or written form,

- deal with technical and non-technical problems that may occur during the implementation of a project lasting several weeks,
- demonstrate teamwork and leadership skills,
- utilise project and risk management to support target achievement,
- critically question the objectives of the project and find a balance to support an overall success of the project,
- convincingly present project results in front of an audience,
- write a focused report containing analysis, solution concept and implementation of the project.

Content:

Working on a team project in the field of AI engineering and autonomous systems.

Potential topics are compiled every semester, according to current research topics of THI professors, assistants, lab or research facilities as well as project offers from companies.

Project management and organisation are carried out by students. The lecturer only acts as a coach, mentor, and/or client. The project management method can be classical or agile. The decision about which method to use is up to the project team.

At the beginning of the project, the lecturer clearly communicates expectations regarding the deadlines as well as type and scope of deliverables to be provided by the team. Frequency and duration of planning sessions as well as work meetings are to be discussed.

Literature:

- will be announced by lecturer at the beginning of the project

Additional remarks:

None

Master Thesis

Module abbreviation:	AI_MasterThesis	**Reg.no.:**	13
Curriculum:	**Programme**	**Module type**	**Semester**
	AI Engineering of Autonomous Systems (SPO WS 23/24)	Compulsory Subject	3
Module frequency:	winter and summer term	**Duration:**	1 semester
Responsible for module:	Mecking, Michael		
Lecturer:	All lecturers (AI_MasterThesis) All lecturers (AI_ThesisColl)		
Language of instruction:	English	**Language of exam:**	English
Credit points / SWS:	30 ECTS / 0 SWS		
Workload:	Contact hours: 0 h Self-study: 750 h Total: 750 h		
Subjects of the module:	13.1: Master Thesis 13.2: Colloquium		
Lecture types:	Master Thesis: Prj - project Colloquium: S - seminar		
Availability of the module:	None		

Examinations:

Master Thesis: Master-Thesis
Colloquium:

Further explanations regarding examinations:

In general, students look for a topic for their Master's thesis on their own. Potential topics are either offered internally by university lecturers in notices/online or result from the cooperation of the student with a company.

In the case of an externally provided topic, the student must convince a university lecturer of his or her topic so that the lecturer assumes the role of first examiner. For this purpose, it is advisable to outline the topic and the planned approach in a short exposé.

Prerequisites according examination regulation:

None

Recommended prerequisites:

Successful participation in Scientific Seminar as well as Team Project

Objectives:

After successfully completing the master's thesis, students are able to

- to work on a complex engineering problem from the subject area of the study program within a limited period of time and a possibly given budget according to scientific methods in a qualified and independent manner,
- systematically and creatively develop solutions for similar problems,
- determine and evaluate the limits of the solution presented,

- to prepare the problem definition, its classification in an overall context as well as a presentation and discussion of the problem solution and the results in compliance with the rules for scientific texts (stringency, transparency, etc.) and formal criteria,
- follow good scientific practice and apply scientific working methods.

Content:

The master's thesis is a graduation thesis in engineering specific to the course of study. The topic of the master's thesis is set, supervised and accompanied in terms of content by a THI professor. The topic can be worked on in practice, e.g. in a company, or in research at the THI and includes

- scientific analysis of a complex problem specific to the course of study against the background of the state of the art in science and technology,
- literature research, especially considering current international publications in scientific journals,
- development of a creative solution concept appropriate to the context of the problem, taking into account current scientific, technical and operational aspects,
- comprehensive evaluation of alternative solution concepts and selection of the best solution concept (technical, economic evaluation),
- implementation of the selected solution concept of the complex problem specific to the course of study,
- critical and comprehensive analysis of the obtained results using appropriate engineering methods,
- project management (especially time and, if necessary, budget management),
- comprehensible and formally correct presentation and documentation of the solution and results,
- good scientific practice and scientific working methods.

Literature:

Will be specified at the beginning

Additional remarks:

Keep your supervisors and primary examiners regularly informed of your progress. In particular, clarify their expectations regarding the content of the thesis. A whole semester is estimated for working on the Master's thesis (30 ECTS) which in terms of scope and content of a Master's thesis has much higher requirements than a Bachelor's thesis. In particular, the scientific character should be emphasised more strongly in a Master's thesis:

- statements should, wherever possible, be placed in the context of relevant technical literature,
- in addition to conventional technical literature, sources from current research (e.g., dissertations and conference papers) should be substantially included,
- the graduate's working methods should be purposeful, methodical, and systematic, and should be explicitly documented in the thesis,
- quantitative statements, such as measurements, should be investigated and documented using the tools of mathematical statistics.