# Module handbook

## Bachelor's Degree Programme

# ROBOTICS

(IRO)

*Editing state: July 2021*

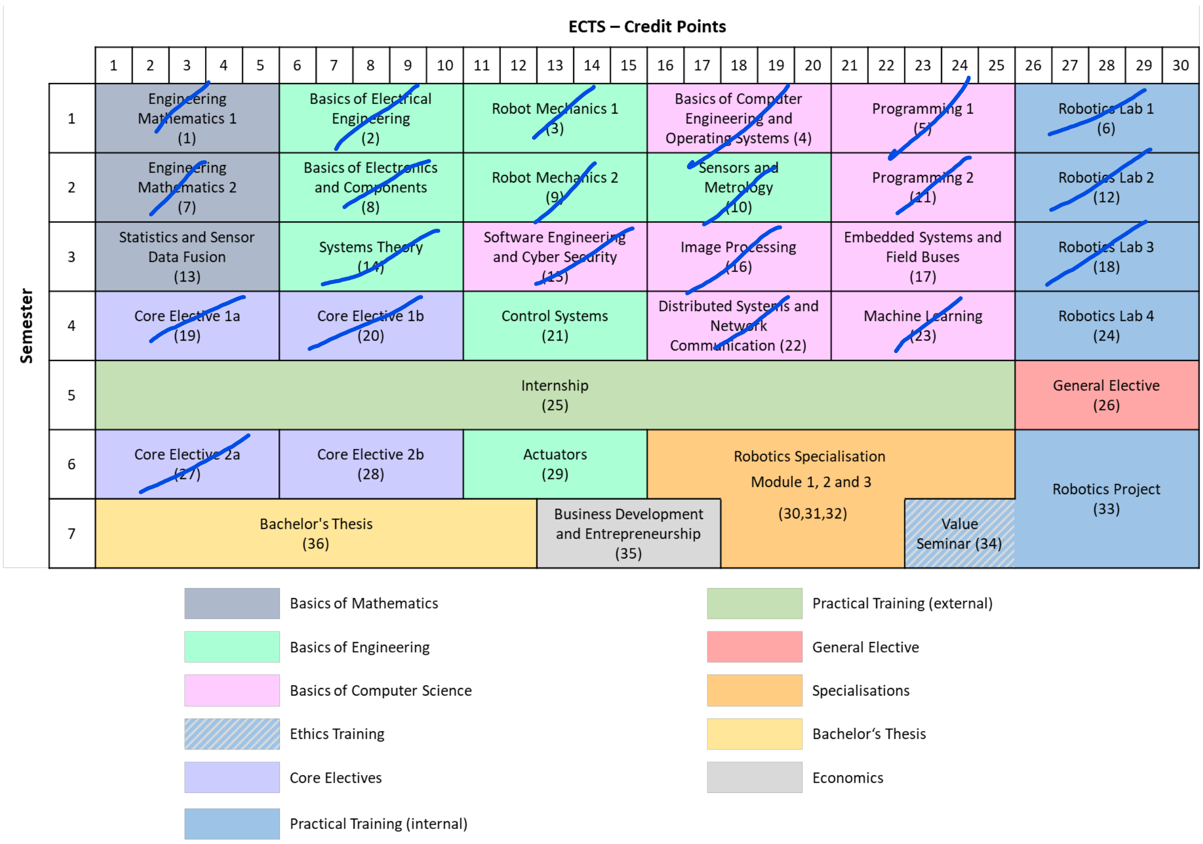
# 1 Study plan and matrix of learning objectives

## 1.1. Study plan of the Bachelor's degree programme Robotics

The study plan for the Bachelor's programme Robotics is described in three variants:

- Graphical representation of the course of studies, based on ECTS points and thus to the workload of the students.
- Graphical representation of the course of study, based on semester hours per week (SWS) and thus the students' planned attendance time
- Tabular representation of modules and courses with allocation to individual semesters and information about the corresponding examination types.

**Structure and modular organisation of the programme (based on ECTS points)**



## Courses and attendance times (represented in contact hours per week (SWS))

<table>
<tr><th></th><th colspan="28">Contact hours per week (SWS)</th></tr>
<tr><th>Semester</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th><th>21</th><th>22</th><th>23</th><th>24</th><th>25</th><th>26</th><th>27</th><th>28</th></tr>
<tr><td>1</td><td colspan="6">Engineering Mathematics 1 (1)</td><td colspan="6">Basics of Electrical Engineering (2)</td><td colspan="4">Robot Mechanics 1 (3)</td><td colspan="4">Basics of Computer Engineering and Operating Systems (4)</td><td colspan="4">Programming 1 (5)</td><td colspan="4">Robotics Lab 1 (6)</td></tr>
<tr><td>2</td><td colspan="6">Engineering Mathematics 2 (7)</td><td colspan="6">Basics of Electronics and Components (8)</td><td colspan="4">Robot Mechanics 2 (9)</td><td colspan="4">Sensors and Metrology (10)</td><td colspan="4">Programming 2 (11)</td><td colspan="4">Robotics Lab 2 (12)</td></tr>
<tr><td>3</td><td colspan="4">Statistics and Sensor Data Fusion (13)</td><td colspan="4">Systems Theory (14)</td><td colspan="4">Software Engineering and Cyber Security (15)</td><td colspan="4">Image Processing (16)</td><td colspan="4">Embedded Systems and Field Buses (17)</td><td colspan="4">Robotics Lab 3 (18)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td colspan="4">Core Elective 1a (19)</td><td colspan="4">Core Elective 1b (20)</td><td colspan="4">Control Systems (21)</td><td colspan="4">Distributed Systems and Network Communication (22)</td><td colspan="4">Machine Learning (23)</td><td colspan="4">Robotics Lab 4 (24)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>5</td><td colspan="4">General Elective (26)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td colspan="4">Core Elective 2a (27)</td><td colspan="4">Core Elective 2b (28)</td><td colspan="4">Actuators (29)</td><td colspan="8">Robotics Specialisation Module 1 + 2 (30, 31)</td><td colspan="5">Robotics Project (33)</td><td></td><td></td><td></td></tr>
<tr><td>7</td><td colspan="4">Business Development and Entrepreneurship (35)</td><td colspan="4">Robotics Specialisation Module 3 (32)</td><td colspan="2">Value Seminar (34)</td><td colspan="5">Robotics Project (33)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

- Basics of Mathematics
- Basics of Engineering
- Basics of Computer Science
- Ethics Training
- Core Electives
- Practical Training (internal)
- Practical Training (external)
- General Elective
- Specialisations
- Bachelor's Thesis
- Economics

## 1.2. Tabular representation of modules

| No. | Module name | Sem. | SWS | ECTS-Points | Course type | Condi-tion | Examination | | Weighting | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Type | Dura-tion/format | Factor | Actual weight |
| | **Semester 1** | | | | | | | | | |
| 1 | Engineering Mathematics 1 | 1 | 6 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 2 | Basics of Electrical Engineering | 1 | 6 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 3 | Robot Mechanics 1 | 1 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 4 | Basics of Computer Engineering and Operating Systems | 1 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 5 | Programming 1 | 1 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 6 | Robotics Lab 1 | 1 | 4 | 5 | S, LP | | soP | H (m.E./o.E.) | 0 | 0 |
| | | | | | | | | | | |
| | **Semester 2** | | | | | | | | | |
| 7 | Engineering Mathematics 2 | 2 | 6 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 8 | Basics of Electronics and Components | 2 | 6 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 9 | Robot Mechanics 2 | 2 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 10 | Sensors and Metrology | 2 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 11 | Programming 2 | 2 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 12 | Robotics Lab 2 | 2 | 4 | 5 | S, LP | | soP | H (m.E./o.E.) | 0 | 0 |
| | | | | | | | | | | |
| | **Semester 3** | | | | | | | | | |
| 13 | Statistics and Sensor Data Fusion | 3 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 14 | Systems Theory | 3 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 15 | Software Engineering and Cyber Security | 3 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 16 | Image Processing | 3 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 17 | Embedded Systems and Field Buses | 3 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 18 | Robotics Lab 3 | 3 | 4 | 5 | S, LP | | soP | H (m.E./o.E.) | 0 | 0 |
| | | | | | | | | | | |
| | **Semester 4** | | | | | | | | | |
| 19 | Core Elective 1a | 4 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 20 | Core Elective 1b | 4 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 21 | Control Systems | 4 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 22 | Distributed Systems and Network Communica-tion | 4 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 23 | Machine Learning | 4 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 24 | Robotics Lab 4 | 4 | 4 | 5 | S, LP | | soP | H (m.E./o.E.) | 0 | 0 |
| | | | | | | | | | | |
| | **Semester 5** | | | | | | | | | |
| 25 | Internship | 5 | 0 | 25 | P | 90 ECTS-Points | | (m.E./o.E.) | 0 | 0 |
| 26 | General Elective | 5 | 4 | 5 | * | | * | * | 1 | 5 |
| | | | | | | | | | | |
| | **Semester 6 and 7** | | | | | | | | | |
| 27 | Core Elective 2a | 6 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 28 | Core Elective 2b | 6 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 29 | Actuators | 6 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 30 | Robotics Specialisation Module 1 | 6 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 31 | Robotics Specialisation Module 2 | 6 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 32 | Robotics Specialisation Module 3 | 7 | 4 | 5 | SU, Ü | | sP | 90-120 min | 1 | 5 |
| 33 | Robotics Project | 6 u. 7 | 10 | 10 | S, Pro | | soP | A (m.E./o.E.) | 0 | 0 |
| 34 | Values Seminar | 7 | 2 | 3 | S | | soP | C (m.E./o.E.) | 0 | 0 |
| 35 | Business Development and Entrepreneurship | 7 | 4 | 5 | S | | soP | G | 1 | 5 |
| 36 | Bachelor's Thesis | 7 | 0 | 12 | - | 150 ECTS-Points + module 25 | BA | | 1 | 12 |
| | | | | | | | | | | |
| | **Total:** | | **148** | **210** | | | | | | **152** |

**BA** Bachelor's thesis
**ECTS** European Credit Transfer and Accumulation System
**LP** Lab course
**m.E./o.E.** Passed successfully/failed
**P** Internship
**Pro** Project
**S** Seminar
**soP** Other type of assessment
A Project work
C Presentation
G Portfolio assignment
H Practical assignment
**sP** Written examination
**SU** Seminar-like lecture
**SWS** Contact hours per week
**Ü** Exercise course

## 1.3. Alternative study variants

The course of study is shown in the following illustration. There are two different variants to choose from. The study programme advisor is available for all questions that may arise in connection with the variants.

<table>
<tr><th colspan="15">Bachelor’s Degree Programme Robotics – Study Variants</th></tr>
<tr><td colspan="15"></td></tr>
<tr><td>Semester</td><td colspan="2">1</td><td colspan="2">2</td><td colspan="2">3</td><td colspan="2">4</td><td colspan="2">5</td><td colspan="2">6</td><td colspan="2">7</td></tr>
<tr><td>Study Plan</td><td colspan="8">Basic studies</td><td colspan="2">Internship semester</td><td colspan="4">Subject and Speciali-sation studies</td></tr>
<tr><td rowspan="2">Variant A</td><td rowspan="2">GS</td><td rowspan="2">X</td><td rowspan="2">GS</td><td rowspan="2">X</td><td rowspan="2">GS</td><td rowspan="2">X</td><td rowspan="2">GS</td><td rowspan="2">X</td><td rowspan="2">PS</td><td rowspan="2">X</td><td rowspan="2">FV</td><td>X</td><td>FV</td><td rowspan="2">X</td></tr>
<tr><td colspan="2">BA</td></tr>
<tr><td rowspan="2">Variant B</td><td rowspan="2">GS</td><td rowspan="2">X</td><td rowspan="2">GS</td><td rowspan="2">X</td><td rowspan="2">GS</td><td rowspan="2">X</td><td rowspan="2">GS</td><td rowspan="2">X</td><td rowspan="2">PS</td><td rowspan="2">X</td><td rowspan="2">FV</td><td rowspan="2">X</td><td>FV</td><td>X</td></tr>
<tr><td colspan="2">BA</td></tr>
</table>

*Variant A:* *Start of the Bachelor's thesis at the end of the subject and specialisation studies in the 6th semester.*

*Variant B:* *Start of the Bachelor's thesis at the beginning of the 7th semester (Attention: BA grade may not be awarded until the 8th semester).*

| | |
|---|---|
| GS | Basic phase modules |
| X | Semester break |
| PS | Internship phase |
| FV | Subject and specialisation phase modules |
| BA | Bachelor’s thesis |

## 1.4. Matrix of Learning Objectives

The matrix presented below provides an overview of the overarching learning objectives to be achieved with the modules. The concrete learning objectives and contents of the individual modules are described in the module descriptions that follow in sections 2, 3 and 4.

**Professional, methodological, personal and social competences, 1st to 3rd semester**

| | 1st semester | | | | | | 2nd semester | | | | | | 3rd semester | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Engineering Mathematics 1 | Basics of Electrical Engineering | Robot Mechanics 1 | Basics of Computer Eng. and OS | Programming 1 | Robotics Lab 1 | Engineering Mathematics 2 | Basics of Electronics and Components | Robot Mechanics 2 | Sensors and Metrology | Programming 2 | Robotics Lab 2 | Statistics and Sensor Data Fusion | Systems Theory | Software Eng. und Cyber Security | Image Processing | Embedded Systems and Field Buses | Robotics Lab 3 |
| **Professional competence** | | | | | | | | | | | | | | | | | | |
| Math.-natural science competence | X | | | | | | X | | | | | | X | | | | | |
| Engineering competence | | X | X | X | X | X | | X | X | X | X | X | | X | X | X | X | X |
| Spec. eng. professional competence | | | | | | | | | | | | | | | | | | |
| Foreign lang. competence English | | | | | | | | | | | | | | | | | | |
| **Methodological competence** | | | | | | | | | | | | | | | | | | |
| Scientific working competence | | | | | | | | | | | | | | | | | | |
| Problem-solving competence | | | | | X | X | | | | | X | X | | | | | | X |
| Presentation skills | | | | | | | | | | | | | | | | | | |
| Moderation skills | | | | | | | | | | | | | | | | | | |
| Transfer competence | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| **Personal competence** | | | | | | | | | | | | | | | | | | |
| Self-reflection | | | | | | X | | | | | | X | | | | | | X |
| Value awareness | | | | | | | | | | | | | | | | | | |
| Flexibility | | | | | | X | | | | | | X | | | | | | X |
| Creativity | | | | | | X | | | | | | X | | | | | | X |
| Responsibility | | | | | | X | | | | | | X | | | | | | X |
| **Social competence** | | | | | | | | | | | | | | | | | | |
| Communication competence | | | | | | X | | | | | | X | | | | | | X |
| Team and cooperation skills | | | | | | X | | | | | | X | | | | | | X |
| Intercultural competence | | | | | | | | | | | | | | | | | | |
| Conflict resolution skills | | | | | | X | | | | | | X | | | | | | X |
| Leadership competence | | | | | | X | | | | | | X | | | | | | X |
| Decision-making competence | | | | | | X | | | | | | X | | | | | | X |

## Professional, methodological, personal and social competences, 4th to 7th semester

| | 4th semester | | | | | 5th sem. | | 6th and 7th semester | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Core Elective 1a | Core Elective 1b | Control Systems | Distributed Syst. and Network Comm. | Robotics Lab 4 | Internship | General Elective | Core Elective 2a | Core Elective 2b | Actuators | Robotics Specialisation Modules | Robotics Project | Value Seminar | Business Dev. and Entrepreneurship | Bachelor´s Thesis |
| **Professional competence** | | | | | | | | | | | | | | | |
| Math.-natural science competence | | | | | | | | | | | | | | | |
| Engineering competence | | | X | X | X | | | | | X | | X | | | |
| Spec. eng. professional competence | X | X | | | | X | | X | X | | X | | | | X |
| Foreign lang. competence English | | | | | | X | X | | | | | | | | |
| **Methodological competence** | | | | | | | | | | | | | | | |
| Scientific working competence | | | | | | | | | | | | X | | | X |
| Problem-solving competence | X | X | | X | X | X | | X | X | X | X | X | | X | X |
| Presentation skills | | | | | | X | | | | | | X | | X | X |
| Moderation skills | | | | | | | | | | | | X | | | |
| Transfer competence | X | X | X | | X | X | X | X | X | X | X | X | | X | X |
| **Personal competence** | | | | | | | | | | | | | | | |
| Self-reflection | | | | | X | X | | | | | | X | X | | |
| Value awareness | | | | | | | | | | | | X | X | X | |
| Flexibility | | | | | X | X | | | | | | X | X | | X |
| Creativity | | | | | X | X | | | | | | X | X | | X |
| Responsibility | | | | | X | X | | | | | | X | | | X |
| **Social competence** | | | | | | | | | | | | | | | |
| Communication competence | | | | | X | X | | | | | X | X | | | X |
| Team and cooperation skills | | | | | X | X | | | | | X | X | | | X |
| Intercultural competence | | | | | | X | | | | | | X | | | |
| Conflict resolution skills | | | | | X | | | | | | | X | | | |
| Leadership competence | | | | | X | | | | | | | X | | | |
| Decision-making competence | | | | | X | X | | | | | X | X | | | X |

## 2 Basic study phase, 1st to 4th semester

### Module No. 1

### Engineering Mathematics 1

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Kai Diethelm

**Lecturer(s):**

Prof. Dr. K. Diethelm

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Engineering Mathematics 1 | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor’s programme Robotics (Core module, 1st semester)

| | |
|---|---|
| Provides the basis for module(s): | Engineering Mathematics 2 (7) |
| Builds up on module(s): | None |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Inhalte des Unterrichtsfaches Mathematik der Fachoberschulen (o.ä.)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- name the most important terms, especially of linear algebra and elementary mathematics: vectors, matrices, complex numbers, partial fraction decomposition
- use vector operations for calculations
- use matrix operations for calculations
- use complex numbers for calculations
- calculate eigenvalues and eigenvectors
- express real fractional functions by their partial fraction decomposition.
- use elementary functions
- calculate limits
- calculate derivatives and linearisations of functions
- use components of mathematics to solve elementary engineering problems.

**Contents**

- Vectors in space
- Matrices

- Coordinate transformations
- Complex numbers
- Partial fraction decomposition
- Functions
- Limits
- Differential calculus in one variable

**Literature and other learning resources**

- K.A. Stroud and Dexter J. Booth: Engineering Mathematics - Palgrave Macmillan (Publisher) 7th edition, 2013.
- James Stewart: Calculus - Cengage Learning (Publisher), 7th edition, 2012.

**Special notes**

## Module No. 2

## Basics of Electrical Engineering

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Bettina Brandenstein-Köth

**Lecturer(s):**

Prof. Dr. V. Willert

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Basics of Electrical Engineering | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 1st semester)

| | |
|---|---|
| Provides the basis for module(s): | Basics of Electronics and Components (8) |
| Builds up on module(s): | None |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

None

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- define the basic terms of electrical engineering
- describe the physical relationships in direct current networks
- name different methods of analysis for the calculation of linear networks
- apply complex numbers to calculate single-phase and three-phase AC networks
- describe the behaviour of passive components
- calculate the frequency behaviour of simple, analogue filters

**Contents**

- Fundamental concepts of electrical engineering (electrical circuits, Ohm's law, equivalent circuits, energy and power)
- Basic circuit theorems (Kirchhoff's circuit laws, network conversions)
- Systematic analysis of linear networks
- Fundamental concepts of alternating current, representation as complex pointers
- Frequency behaviour of electronic circuits, analogue filters
- Fundamentals of three-phase systems

**Literature and other learning resources**

- T. L. Floyd, Principles of Electric Circuits, Pearson, 2016.
- J. Nilsson and S. Riedel, Electric Circuits, Pearson, 2014.
- C. Alexander and M. Sadiku, Fundamentals of Electric Circuits, McGraw-Hill Education, 2012.
- John O'Malley, Schaum's Outline of Basic Circuit Analysis, McGraw-Hill Education, 2011.
- Mahmood Nahvi, Schaum's Outline of Electric Circuits, McGraw-Hill Education, 2013.

**Special notes**

## Module No. 3

## Robot Mechanics 1

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr.-Ing. Jean Meyer

**Lecturer(s):**

Prof. Dr.-Ing. J. Meyer

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Robot Mechanics 1 | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 1st Semester)

| | |
|---|---|
| Provides the basis for module(s): | Robot Mechanics 2 (9), „Industrial Robotics“ specialisation modules |
| Builds up on module(s): | None |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

School knowledge of higher mathematics and physics

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- name relevant quantities of statics and dynamics
- use methods to reduce forces and moments
- apply the principle of sections
- formulate the equilibrium conditions for central and general systems of forces
- analyse the forces in statically loaded rigid body systems
- calculate the centre of volume and the centre of mass of bodies
- analyse static and dynamic friction forces
- calculate the translational and rotational movements of points and rigid bodies, including the associated forces and moments
- investigate the moment of inertia of non-symmetrical objects
- use the work theorem to describe motion processes
- use relevant quantities to describe the position, velocity and acceleration of objects in cartesian coordinates and polar coordinates

**Contents**

- Reduction of forces and moments

- Addition and decomposition of forces
- Equilibrium in central and general systems of forces
- Calculation of support and joint reactions
- Calculation of centre of gravity
- Trusses
- Static and dynamic friction
- Work, energy, power and efficiency
- Kinematics of point masses
- Planar kinetics of point masses and of rigid bodies
- Mass moments of inertia
- Principle of linear and angular momentum

**Literature and other learning resources**

- Gross, Hauger, Schröder, Wall, Rajapakse: Engineering Mechanics 1: Statics, Springer, 2nd edition, 2013.
- Gross, Hauger, Schröder, Wall, Govindjee: Engineering Mechanics 3: Dynamics, Springer, 2nd edition, 2014

**Special notes**

## Module No. 4

## Basics of Computer Engineering and Operating Systems

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Heinz Endres

**Lecturer(s):**

Prof. Dr. M. Bodewig, Prof. Dr. M. Mathes

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Basics of Computer Engineering and Operating Systems | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor’s programme Robotics (Core module, 1st semester)

| | |
|---|---|
| Provides the basis for module(s): | Embedded Systems and Field Buses (17), Distributed Systems and Network Communication (22) |
| Builds up on module(s): | None |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

School knowledge of higher mathematics

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- name the elements and the structure of digital circuits.
- analyse simple circuits and complex, finite-state machines
- describe the function and operation of today's operating systems
- apply the concepts of processes and threads
- name methods for scheduling and synchronising processes and threads
- recognise deadlocks and develop solutions to deal with them
- apply algorithms for managing free memory and using virtual memory
- list tasks of the operating system in the area of input and output and the management of external data storages and file systems
- list basic requirements for the security and protection of data.

**Contents**

Basics of Computer Engineering:

- Binary and hexadecimal number representation
- Addition and subtraction in the binary system

- Calculation rules of the Boolean algebra
- Digital circuit design and important basic circuits
- Time-dependent circuits and flip-flops
- Finite-state machines, combinational and sequential logic

Operating Systems:

- Interrupts
- Processes and Threads
- Synchronization and Deadlocks
- Memory Management
- File Systems
- Input/Output
- Security

**Literature and other learning resources**

- Michael Collier, Svetlana Bebova, Wendy Weu, Digital Circuit Design: Principles and Practice, Collier Creations, 1st edition, 2014
- Anil K. Maini, Digital Electronics: Principles, Devices and Applications, John Wiley & Sons Ltd., 1st edition, 2007
- Neil Weste, David M. Harris, CMOS VLSI Design: A Ciruits and Systems Perspective, Pearson Education Inc., 4th edition, 2010
- Andrew S. Tanenbaum: Moderne Betriebssysteme, 4th edition, Pearson Education, 2015.
- Christian Baun: Operating Systems / Betriebssysteme, Springer Nature, 2020.
- William Stallings: Operating Systems, 7th edition, Prentice Hall, 2012.

**Special notes**

# Module No. 5

## Programming 1

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Norbert Strobel

**Lecturer(s):**

Prof. Dr. N. Strobel

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Programming 1 | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 1st semester)

| | |
|---|---|
| Provides the basis for module(s): | Programming 2 (11) |
| Builds up on module(s): | None |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

None

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- list basic terms of computer science
- name different programming paradigms and their advantages and disadvantages for different problems
- use the programming language C++ to store information with the help of different data types
- apply elementary language constructs and control structures in C++
- develop independent programme units
- evaluate concept solutions for engineering tasks

**Contents**

- Objectives and subfields of computer science
- Comparison of different programming paradigms
- Concept of the algorithm
    - Time complexity
    - Space complexity
- Tool Chain: compiler, preprocessor, interpreter, IDE, shell
- Procedural programming:

  - Elementary data types
  - Expressions
  - Instructions
  - Control structures (loops and branches)
  - Modularization via functions
  - Call-by-value and call-by-reference
  - Visibility areas and programme structuring
  - Elementary data structures (fields, structures, associations)
- Optional:
  - Introduction to microcontroller programming
  - selected algorithmic problems of robotics

**Literature and other learning resources**

- C. Horstmann, C++ for Everyone, Wiley, 2011.
- P. Deitel, C++ How to Program (Early Objects Version), Pearson, 2017.
- W. Savitch, Problem Solving with C++, Pearson, 2015.
- P. Deitel, C: How to Program, Pearson, 2009.
- H. Herold, B. Lurz, J. Wohlrab, Grundlagen der Informatik, Pearson, 2007 (in German).
- Online reference for C++: https://en.cppreference.com/w/

**Special notes**

# Module No. 6

## Robotics Lab 1

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>90 hrs self-directed study time | 5 |

**Responsible for module:** Prof. Dr. Jean Meyer

**Lecturer(s):**

Prof. Dr. N. Strobel, Prof. Dr. T. Kaupp, Prof. Dr. R. Herrler, Prof. Dr. J. Meyer

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Robotics Lab 1 | Seminar and lab course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 1st semester)

| | |
|---|---|
| Provides the basis for module(s): | Robotics Lab 2 (12) |
| Builds up on module(s): | None |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

None

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Other type of assessment | --- | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- apply the theoretical knowledge from modules of the semester in practical course units and experiments
- select suitable methods from the lectures for conducting the practical experiments
- apply robotics-relevant software tools
- use software tools for the development and application of robots
- analyse processes and methods in the context of practical experiments
- plan experiments, carry them out and document the results in a scientific format
- interpret experimental results and draw conclusions from them with regard to the underlying influencing factors and cause-effect relationships

**Contents**

- Occupational health and safety instruction
- Basics of soft soldering
- Application of microcontrollers and electronic components
- Circuit design with microcontrollers and electronic components
- Programming of cobots via teach pendant
- Introduction to Matlab
- Measurement technology lab: Measurement of current and voltage

**Literature and other learning resources**

| |
|---|
| • Experimental instructions, lab manuals and supplementary documents on the FHWS eLearning system. |
| **Special notes** |
| |

## Module No. 7

## Engineering Mathematics 2

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Kai Diethelm

**Lecturer(s):**

Prof. Dr. K. Diethelm

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Engineering Mathematics 2 | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 2nd semester)

| | |
|---|---|
| Provides the basis for module(s): | Statistics and Sensor Data Fusion (13) |
| Builds up on module(s): | Engineering Mathematics 1 (1) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Engineering Mathematics 1 (1)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- name the most important terms, especially of elementary analysis: Integral calculus of a variable, Fourier series, functions of multiple variables
- calculate (oriented) areas
- calculate Fourier series of periodic functions
- use differential calculus for optimisation
- calculate multiple integrals
- solve linear ordinary differential equations (and systems) using Laplace transformations
- use components of mathematics to solve elementary engineering problems.

**Contents**

- Integral calculus in a single variable
- Fourier series
- Functions of multiple variables
- Differential calculus in multiple variables
- Multiple integrals
- Differential equations

| |
|---|
| • Laplace transforms |
| **Literature and other learning resources** |
| • K.A. Stroud and Dexter J. Booth: Engineering Mathematics - Palgrave Macmillan (Publisher) 7th edition, 2013.<br>• James Stewart: Calculus - Cengage Learning (Publisher), 7th edition, 2012. |
| **Special notes** |
| |

## Module No. 8

## Basics of Electronics and Components

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Volker Willert

**Lecturer(s):**

Prof. Dr. V. Willert

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Basics of Electronics and Components | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 2nd semester)

| | |
|---|---|
| Provides the basis for module(s): | None |
| Builds up on module(s): | Basics of Electrical Engineering (2) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Basics of Electrical Engineering (2)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- state the physical principles for calculating electric and magnetic fields
- construct, calculate and draw electric and magnetic fields
- state the most important passive components and name their properties
- define the physical principles of semiconductor components
- list the properties of bipolar and field effect transistors
- calculate the impedance of electrical circuits made of passive components
- design circuits for diodes and transistor amplifiers and analyse their properties

**Contents**

- Electric and magnetic fields
- Induction
- Passive components
- Active components
- Semiconductor components
- Circuit engineering

| Literature and other learning resources |
|---|
| • Hering, Martin, Storer: Physik für Ingenieure, Berlin-Heidelberg, Springer Verlag, 2012<br>• Wilfried Weißgerber, Elektrotechnik für Ingenieure 1: Gleichstromtechnik und Elektromagnetisches Feld, 8. Auflage, Vieweg & Teubner, 2008.<br>• Wilfried Weißgerber: Elektrotechnik für Ingenieure 2: 8. Auflage, Vieweg & Teubner, 2008.<br>• Siegfried Altmann, Detlef Schlayer: Lehr- und Übungsbuch Elektrotechnik, 4. Auflage, Hanser Verlag München, 2008.<br>• Hering, Martin, Storer: Physik für Ingenieure, Berlin-Heidelberg, Springer Verlag, 2012<br>• U. Tietze, Ch. Schenk: Halbleiter-Schaltungstechnik, 12. Auflage, Berlin-Heidelberg-New York, Springer Verlag, 2002 |
| **Special notes** |
| |

## Module No. 9

## Robot Mechanics 2

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Volker Willert

**Lecturer(s):**

Prof. Dr. V. Willert

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Robot Mechanics 2 | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 2nd semester)

| | |
|---|---|
| Provides the basis for module(s): | Robotics Lab 3 and 4 (18 and 24), Robotics Project (33), „Industrial Robotics“ specialisation modules |
| Builds up on module(s): | Robot Mechanics 1 |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Robot Mechanics 1 (3)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- describe robot kinematics and their mechanical and electrical components
- name typical fields of application of robots as well as their application limits
- use the Denavit-Hartenberg convention to describe robot kinematics
- use the Denavit-Hartenberg parameters for coordinate transformation
- calculate the direct and inverse kinematics of a simple robot
- evaluate the suitability of robot grippers for different handling tasks
- describe different robot programming methods and types of robot movement commands
- name fields of application and application limits of human-robot collaboration

**Contents**

- Historical development
- Classification of robots
- Parts/components
- State of the art + trends and developments
- Economic aspects

- Application examples according to platforms
- Basics of effectors
- Basics of actuators
- Basics of robot programming
- Coordinate systems
- Description of rotations (rotation matrix, Euler angle, rotation vector)
- Transformation matrices / coordinate transformation
- Denavit-Hartenberg convention
- Forward and backward kinematics
- Human-robot collaboration

**Literature and other learning resources**

- SICILIANO, B.: Springer handbook of robotics, Springer Science & Business Media, 2008
- CORKE, Peter. Robotics, vision and control: fundamental algorithms in MATLAB® second, completely revised. Springer, 2017

**Special notes**

## Module No. 10

## Sensors and Metrology

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Jürgen Hartmann

**Lecturer(s):**

Prof. Dr. J. Hartmann, Prof. Dr. J. Meyer

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Sensors and Metrology | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 2nd semester)

| | |
|---|---|
| Provides the basis for module(s): | Robotics Lab 3 and 4 (18 and 24), Specialisation modules |
| Builds up on module(s): | Basics of Electrical Engineering (2) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Basics of Electrical Engineering (2)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- classify sensors according to technical and application-related characteristics
- name conversion principles of sensors
- describe methods of signal processing from the analogue electrical raw signal to the digital value
- list different types of proximity switches
- describe the function of sensors for angle and distance measurement as well as other kinematic quantities
- describe the function of sensors for force and torque measurement
- evaluate the suitability of sensors on the basis of relevant parameters for different measuring tasks
- describe the function of sensors for localisation
- select suitable sensors for HRC workstations
- describe the function of 2D and 3D imaging sensors, including analytical models for generating depth images
- select suitable metrological methods in a robotics-relevant context
- calculate the error of metrological systems
- name methods for processing measurement data
- analyse metrological systems

- develop mathematical models to solve metrological tasks independently of the technical system characteristics
- describe the functional principle of A/D and D/A conversion and the circuit implementation
- plan steps for the mathematical modelling of metrological systems
- describe the use of measuring bridges and operational amplifiers

**Contents**

Sensors:

- Classification of sensors
- Conversion principles (thermal, mechanical, magnetic, optical)
- Sensor characteristics
- Proximity switches
- Sensors for angle and distance measurement as well as other kinematic quantities
- Sensors for force and torque measurement
- Sensors for localisation
- Sensors for MRK workstations
- 2D and 3D cameras

Metrology:

- Fundamentals of metrology, measuring inaccuracies, error calculation
- Measuring system technology, measurement data processing
- Current and voltage measurement
- Basics of A/D and D/A conversion
- Measuring bridges
- Operational amplifiers

**Literature and other learning resources**

- FRADEN, Jacob. Handbook of modern sensors: physics, designs, and applications. Springer Science & Business Media, 2004
- Bentley, John: Principles of Measurement Systems 4th Edition; Pearson Education, Harlow, 2004
- Beckwit, T.; Marangoni R.; Lienhard, J. V.: Mechanical Measurements, Pearson Education, Harlow, 2006
- Witte, Robert: Electronic Test Instruments, 2nd Edition, Pearson Education, Harlow, 2002
- DIN 1319-1:1995-01 Fundamentals of metrology - Part 1: Basic terminology
- DIN 1319-2:2005-10 Fundamentals of metrology - Part 2: Terminology related to measuring equipment
- DIN 1319-3:1996-05 Fundamentals of metrology - Part 3: Evaluation of measurements of a single measurand, measurement uncertainty
- DIN 1319-4:1999-02 Grundlagen der Messtechnik, Teil 4: Auswertung von Messungen; Meßunsicherheit
- JCGM 100:2008: Guide to the Expression of Uncertainty in Measurement (GUM)

**Special notes**

## Module No. 11

## Programming 2

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Marco Schmidt

**Lecturer(s):**

Prof. Dr. M. Schmidt

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Programming 2 | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 2nd semester)

| | |
|---|---|
| Provides the basis for module(s): | Software Engineering and Cyber Security (15) |
| Builds up on module(s): | Programming 1 (5) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Programming 1 (5)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- Name concepts of object orientation
- Use suitable classes and objects for object-oriented programming
- Indicate possible relationships between classes and objects and put them into practice.
- Describe complex data structures such as lists, stacks and trees using the C++ Standard Library
- Apply advanced concepts such as generic classes and meta-programming as examples

**Contents**

Object-oriented programming

- Objects and classes
- Attributes / methods and their visibility
- Abstraction, inheritance, polymorphism, encapsulation
- Association, Aggregation, Composition
- Pre- and postconditions and invariants of classes
- Overloading methods and operators
- Basic algorithms: search and sort
- Composite data structures: lists, stacks, trees, graphs

- Generic classes
- Meta programming and annotations

Optional
- Algorithms for finding optimal paths
- OO Modeling of a robot system
- Selected algorithmic problems of robotics

**Literature and other learning resources**
- Torsten T. Will: C++ Das umfassende Handbuch, Rheinwerk Computing
- Online reference for C++: https://en.cppreference.com/w/
- P.J. Deitel, H. Deitel, C++ How To Program (Early Objects Version), Pearson, 10th Edition, 2016

**Special notes**

## Module No. 12

## Robotics Lab 2

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>90 hrs self-directed study time | 5 |

**Responsible for module:** Prof. Dr. Jean Meyer

**Lecturer(s):**

Prof. Dr. N. Strobel, Prof. Dr. B. Müller, Prof. Dr. V. Willert, Prof. Dr. J. Meyer

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Robotics Lab 2 | Seminar and lab course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 2nd semester)

| | |
|---|---|
| Provides the basis for module(s): | Robotics Lab 3 (18) |
| Builds up on module(s): | Robotics Lab 1 (6) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Robotics Lab 1 (6)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Other type of assessment | --- | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- apply the theoretical knowledge from modules of the semester in practical course units and experiments
- select suitable methods from the lectures for conducting the practical experiments
- apply robotics-relevant software tools
- use software tools for the development and application of robots
- analyse processes and methods in the context of practical experiments
- plan experiments, carry them out and document the results in a scientific format
- interpret experimental results and draw conclusions from them with regard to the underlying influencing factors and cause-effect relationships

**Contents**

- Advanced programming of microcontrollers with standard C/C++
- Programming of a microcontroller-based line follower with standard C/C++
- Operation of industrial drives
- Introduction to the Matlab Robotics System Toolbox
- Tracking with cameras

**Literature and other learning resources**

- Experimental instructions, lab manuals and supplementary documents on the FHWS eLearning system.

| Special notes |
|---|
| |

## Module No. 13

## Statistics and Sensor Data Fusion

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Gernot Fabeck

**Lecturer(s):**

Prof. Dr. C. Zirkelbach, Prof. Dr. G. Fabeck

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Statistics and Sensor Data Fusion | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 3rd semester)

| | |
|---|---|
| Provides the basis for module(s): | Machine Learning (23), Specialisation modules |
| Builds up on module(s): | Engineering Mathematics 1 (1) and Engineering Mathematics 2 (7) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Engineering Mathematics 1 (1) and Engineering Mathematics 2 (7)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- use the basic terminology of statistics
- name the role and interaction of descriptive statistics, probability theory and inferential statistics
- recognise and classify the implementation of these components in concrete statistical procedures
- describe the analysis of statistical data and the application of probability theory to the analysis of random processes and the methodical implementation of sampling and its evaluation
- distinguish between the different levels of abstraction at which the fusion of data from several sensors can take place
- represent a dynamic system in the state space
- apply the mathematical method of the Kalman filter for the iterative estimation of system parameters on the basis of observations with errors
- define the pattern recognition problem and the Bayes classifier

**Contents**

<u>Statistics:</u>

1. Descriptive Statistics
   - Analysis of univariate data: Measures of central tendency and of dispersion

- Analysis of bivariate data: Analysis of correlation, regression analysis, time series analysis

2. Probability Calculus
   - Fundamental concepts and important rules of probability calculus
   - Random variables: Probability functions and densities, expected value, variance, important calculation rules, important discrete and continuous distributions, law of large numbers, central limit theorem, multivariate distributions, conditional distributions, conditional expected values
3. Inductive Statistics
   - Parameter estimation

Sensor Data Fusion:

1. Types of sensor data fusion
2. State space description of dynamical systems
3. Elements of Bayesian statistics
4. Structure and function of the classical Kalman filter
5. Pattern recognition and Bayes-optimal classifier

**Literature and other learning resources**


- Diez, D. M./Barr, C. D./Çetinkaya-Rundel, M. (2015): OpenIntro Statistics, 3rd edition, Scotts Valley: CreateSpace Independent Publishing Platform.
- Koch, W. (2014): Tracking and Sensor Data Fusion: Methodological Framework and Selected Applications, Berlin: Springer Verlag.
- Ma, H./Yan, L./Xia, Y./Fu M. (2020): Kalman Filtering and Information Fusion, Singapore: Springer & Science Press.
- Schiller, J.J./Srinivasan, R. A./Spiegel, M. R. (2013): Schaum's outline of Probability and Statistics, 4th edition, New York: McGraw-Hill.
- Sullivan, M. (2017): Statistics: Informed Decisions Using Data, 5th edition, London: Pearson.


**Special notes**

## Module No. 14

## Systems Theory

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Bernhard Müller

**Lecturer(s):**
Prof. Dr. R. Hirn, Prof. Dr. B. Müller

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Systems Theory | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 3rd semester)

| | |
|---|---|
| Provides the basis for module(s): | „Mobile Robotics“ specialisation modules |
| Builds up on module(s): | Engineering Mathematics 1 (1) and Engineering Mathematics 2 (7) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Engineering Mathematics 1 (1) and Engineering Mathematics 2 (7)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students
- name basic methods of systems theory
- apply basic methods of systems theory
- develop mathematical description models of technical systems in order to analyse signals and to be able to evaluate the system behaviour independently of the technical system characteristics
- plan and carry out work steps for system analysis
- evaluate their proposed solutions

**Contents**

- Continuous-time signals and systems
- System analysis using Laplace transform
- System analysis using Fourier transform
- Discrete-time signals and systems
- System analysis using z-transform
- System analysis using Discrete Fourier transform
- Stochastic processes, Kalman filter

| Literature and other learning resources |
|---|
| • Oppenheim, Alan V.; Willsksy, Alan S.: Signals and Systems, Pearson Education Ltd., 2nd Edition, Harlow, 2013<br>• Giron-Sierra, Jose Maria: Digital Signal Processing with Matlab Examples 1, Springer Verlag, Berlin, 2016<br>• B.P. Lathi, „Linear Systems and Signals“, 2. Edition, Oxford University Press, 2005<br>• Oppenheim, Alan V.; Schafer, Ronald W.: Discrete-time Signal Processing, Pearson Educatin Ltd., 3rd Edition, 2010 |
| **Special notes** |
| |

## Module No. 15

## Software Engineering and Cyber Security

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Markus Mathes

**Lecturer(s):**

Prof. Dr. M. Mathes

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Software Engineering and Cyber Security | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 3rd semester)

| | |
|---|---|
| Provides the basis for module(s): | Robotics Project (33) |
| Builds up on module(s): | Programming 1 (5) and Programming 2 (11) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Programming 1 (5) and Programming 2 (11)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- give problem-adapted design procedures for software systems
- describe the necessity and the systematic approach to the design and modelling of large-scale software systems
- model software systems at an abstract level
- use relevant methods and techniques to realise and implement the models/designs using appropriate object-oriented programming languages.
- state the advantages of scrambling data packages
- analyse and evaluate procedures with regard to their ability to detect and correct transmission errors
- choose alternatives to establish secure data communication using cryptography
- design encrypted transmissions using simple examples
- indicate basic vulnerabilities in communication systems that can be exploited for hacker attacks
- select suitable countermeasures against hacker attacks
- evaluate the performance of countermeasures against hacker attacks

**Contents**

Software Engineering

- Concepts of object-oriented design: Classes, objects and interfaces, encapsulation, polymorphism, inheritance and delegation
- Object-oriented design with UML, use of elementary diagram types for modelling static and dynamic system aspects
- Object-oriented implementation of software designs
- Agile models on the basis of SCRUM
- Optional: Design pattern

Cyber-Security

- Threats
- Attack procedure
- Security on the Internet
- Symmetric key cryptography
- Asymmetric Key Cryptography
- Hash function
- Packet Sniffing: Wireshark

**Literature and other learning resources**

- Christoph Kecher: UML 2 – Das umfassende Handbuch, Rheinwerk Computing
- Christian Ullenboom: Java ist auch eine Insel, Rheinwerk Computing
- Steffen Heinzl, Markus Mathes: Middleware in Java, Springer Vieweg
- LUDWIG, Mark; NOAH, Dr. The giant black book of computer viruses. American Eagle Books, 2017
- BHAIJI, Yusuf: Network Security Technologies and Solutions, 2008
- ERICKSON, Jon. Hacking: Die Kunst des Exploits. Dpunkt-Verlag, 2008.
- LUDWIG, Mark A. The little black book of computer viruses: The basic technology. American Eagle Publications, 1991.

**Special notes**

## Module No. 16

## Image Processing

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Norbert Strobel

**Lecturer(s):**

Prof. Dr. N. Strobel, Prof. Dr. V. Willert

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Image Processing | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 3rd semester)

| | |
|---|---|
| Provides the basis for module(s): | Core Elective 3D Machine Vision, „Mobile Robotics“ and „Humanoid and Service-Robotics“ specialisation modules |
| Builds up on module(s): | Sensors and Metrology (10) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Sensors and Metrology (10)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- name and describe optical camera systems and associated image formation principles
- list aspects of sampling and quantisation
- distinguish between different image representations and image transformations
- apply different intensity transformations
- perform filter operations in the spatial and frequency domains
- use feature estimation, thresholding and region growing methods to perform segmentation
- handle morphological image processing techniques
- enumerate approaches to motion analysis using 2D images

**Contents**

- Image Formation
  - Image Sensing and Acquisition
  - Sampling and Quantization
  - Image Representations (monochrome, color)
  - Geometric Image Transforms

- Intensity Transformations
    - Point Operations
    - Histogram Processing
- Convolution in the Spatial Domain
- Filtering in the Frequency Domain
- Image Segmentation
    - Point, Line, and Edge Detection
    - Thresholding
    - Region-Based Segmentation
- Morphological Image Processing
- Movement analysis and movement compensation
- Selected case studies

**Literature and other learning resources**

- GONZALES, Rafael C; WOODS, Richard E. Digital Image Processing. Pearson, 2017.
- PETROU, Maria MP; PETROU, Costas. Image processing: the fundamentals. John Wiley & Sons, 2010.
- BURGER, Wilhelm, et al. Principles of digital image processing. London: Springer, 2009.

**Special notes**

## Module No. 17

## Embedded Systems and Field Buses

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Martin Spiertz

**Lecturer(s):**

Prof. Dr. M. Spiertz, Prof. Dr. L. Eckert

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Embedded Systems and Field Buses | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor’s programme Robotics (Core module, 3rd semester)

| | |
|---|---|
| Provides the basis for module(s): | Distributed Systems and Network Communication (22) |
| Builds up on module(s): | Basics of Computer Engineering and Operating Systems (4), Programming 1 and 2 (5 and 11) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Basics of Computer Engineering and Operating Systems (4), Programming 1 and 2 (5 and 11)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- name and evaluate current embedded systems and microcontroller architectures
- classify and analyse different embedded structures
- select suitable embedded systems, design them and realise applications with them
- analyse synchronisation possibilities and error sources on the physical layer
- explain the working principle of the data link layer
- name and evaluate advantages and disadvantages of different bus access methods and
- design bus systems with regard to cycle times, number of participants and other bus properties.

**Contents**

<u>Embedded Systems:</u>

- Fields of application, definitions and requirements of embedded systems and basic functional groups: Mechanics, sensors, information processing, actuators.
- Structure of embedded systems, microcontroller systems/CPU/MCU, hardware/software co-design,
- Simultaneous and parallel task processing, definition of real-time processing, real-time systems

- Development steps for a microcomputer system, embedded development, test and verification environments, software build process
- Interfaces to peripherals, serial interface
- Polling versus event-driven program processing via interrupts
- Exemplary function groups in detail: digital I/O, hardware timer, A/D converter

Fieldbus systems:
- Digital communication on the physical layer
- Data link layer
- Bus access
- Fieldbuses in detail (CAN, Profibus, Profinet, EtherCAT)

**Literature and other learning resources**

- Course books, e.g. Schnell, Gerhard; Bussysteme in der Automatisierungs- und Prozesstechnik, Verlag Vieweg Friedr. + Sohn 2006
- Klaus Wüst: Mikroprozessortechnik: Grundlagen, Architekturen, Schaltungstechnik und Betrieb von Mikroprozessoren und Mikrocontrollern, Verlag Springer 2010
- Helmut Bähring: Anwendungsorientierte Mikroprozessoren: Mikrocontroller und Digitale Signalprozessoren, Vieweg+Teubner Verlag, 2011
- MAHALIK, Nitaigour P. (Hg.). Fieldbus technology: industrial network standards for real-time distributed control. Springer Science & Business Media, 2013.
- KLASEN, Frithjof; OESTREICH, Volker; VOLZ, Michael (Hg.). Industrial Communication with Fieldbus and Ethernet. VDE-Verlag, 2011.
- P. Marwedel, Embedded System Design, 3rd edition. Cham: Springer, 2021.

**Special notes**

## Module No. 18

## Robotics Lab 3

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>90 hrs self-directed study time | 5 |

**Responsible for module:** Prof. Dr. Jean Meyer

**Lecturer(s):**

Prof. Dr. T. Kaupp, Prof. Dr. V. Willert

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Robotics Lab 3 | Seminar and lab course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor’s programme Robotics (Core module, 3rd semester)

| | |
|---|---|
| Provides the basis for module(s): | Robotics Lab 4 (24) |
| Builds up on module(s): | Robotics Lab 2 (12) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Robotics Lab 1 (6) and Robotics Lab 2 (12)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Other type of assessment | --- | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- apply the theoretical knowledge from modules of the semester in practical course units and experiments
- select suitable methods from the lectures for conducting the practical experiments
- apply robotics-relevant software tools
- use software tools for the development and application of robots
- analyse processes and methods in the context of practical experiments
- plan experiments, carry them out and document the results in a scientific format
- interpret experimental results and draw conclusions from them with regard to the underlying influencing factors and cause-effect relationships

**Contents**

- Offline programming and simulation of industrial robots with RoboDK and subsequent validation with real robots
- Vision-based pick-and-place with Cobots
- Introduction to the Matlab Image Processing Toolbox
- Calibration methods for digital cameras

**Literature and other learning resources**

- Experimental instructions, lab manuals and supplementary documents on the FHWS eLearning system

| Special notes |
| --- |
| |

## Module No. 19

## Core Elective 1A

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Dean of studies

**Lecturer(s):**

The lecturers can be found in the descriptions of the individual courses.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| See catalogue Core Elective 1 | Seminar-like lecture, exercise course | English |

*One of the courses from the catalogue specified in the curriculum for module 19 (Core Elective 1A) must be selected. The selected course must be different from the selection for module 20 (Core Elective 1B).*

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core elective module, 4th semester)

| | |
|---|---|
| Provides the basis for module(s): | None |
| Builds up on module(s): | Basic modules of the 1st, 2nd and 3rd semester |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

The recommended conditions of participation and prior knowledge can be found in the descriptions of the individual courses.

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

In the core elective modules, students choose from a catalogue of courses in the fields of robotics according to their preferences and professional expectations. The course-related learning objectives can be found in the descriptions of the individual courses.

**Contents**

The contents can be found in the descriptions of the individual courses.

**Literature and other learning resources**

Die Literaturangaben können den Beschreibungen der einzelnen Lehrveranstaltungen entnommen werden.

**Special notes**

## Module No. 20

## Core Elective 1B

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Dean of studies

**Lecturer(s):**

The lecturers can be found in the descriptions of the individual courses.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| See catalogue Core Elective 1 | Seminar-like lecture, exercise course | English |

*One of the courses from the catalogue specified in the curriculum for module 20 (Core Elective 1B) must be selected. The selected course must be different from the selection for module 19 (Core Elective 1A).*

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core elective module, 4th semester)

| | |
|---|---|
| Provides the basis for module(s): | None |
| Builds up on module(s): | Basic modules of the 1st, 2nd and 3rd semester |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

The recommended conditions of participation and prior knowledge can be found in the descriptions of the individual courses.

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

In the core elective modules, students choose from a catalogue of courses in the fields of robotics according to their preferences and professional expectations. The course-related learning objectives can be found in the descriptions of the individual courses.

**Contents**

The contents can be found in the descriptions of the individual courses.

**Literature and other learning resources**

The literature references can be found in the descriptions of the individual courses.

**Special notes**

# Catalogue Core Elective 1

Catalogue of courses for modules 19 (Core Elective 1A) and 20 (Core Elective 1B). The courses are usually offered in the summer semester.

| Title of the lecture | Responsible for the lecture |
|---|---|
| Simulation of Mechatronic Systems | Prof. Dr. Jean Meyer |
| Digital Signal Processing and State Space Control | Prof. Dr. Bernhard Müller |
| Development Processes and Legal Basics | Prof. Dr. Jean Meyer |

## Core Elective 1

## Simulation of Mechatronic Systems

| Module Length | Regular Cycle | Workload |
|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Responsible for the lecture:** Prof. Dr. Jean Meyer

**Lecturer(s):**

N.N.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Simulation of Mechatronic Systems | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Engineering Mathematics 1 (1), Engineering Mathematics 2 (7), Basics of Electrical Engineering (2), Robot Mechanics 1 (3), Robotics Lab 1 (6)

**Learning objectives**

The students

- state the analogies between the common physical quantities, the descriptive equations and the interconnections of electrical, mechanical and fluid-based transmission elements.
- describe overarching interrelationships in the transmission chain
- represent informally described functional chains of mechatronic sub-systems and overall systems in mathematical models
- use selected modelling tools to develop simulation models of mechatronic systems
- describe the application limits of modelling tools
- state the effect of simulation and model parameters
- set simulation and model parameters in a targeted manner
- check the plausibility of the simulation results obtained
- evaluate the effect of model simplifications (e.g. linearisation).

**Contents**

- Analogies between electrical, mechanical and fluid-based systems according to the potential current and the cross through system
- Standardized procedure for the modeling of physical systems
- Frequently occurring nonlinearities
- Application examples of linear and non-linear mechatronic systems
- Numerical integration algorithms

**Literature and other learning resources**

- Rolf Isermann, Mechatronische Systeme, Springer, Berlin Heidelberg New York, 2.Auflage 2008.
- Rainer Nollau, Modellbildung und Simulation technischer Systeme, Springer Dordrecht, 2009.
- Jörg Kahlert, Einführung in WinFACT, Fachbuchverlag Leipzig im Carl Hanser Verlag, 2009.

**Special notes**

## Core Elective 1

## Digital Signal Processing and State Space Control

| Module Length | Regular Cycle | Workload |
|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Responsible for the lecture:** Prof. Dr. Bernhard Müller

**Lecturer(s):**

Prof. Dr. B. Müller

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Digital Signal Processing and State Space Control | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Engineering Mathematics (1), Engineering Mathematics 2 (7), Basics of Electrical Engineering (2), Basics of Electronics and Components (8), Systems Theory (14)

**Learning objectives**

The students

- describe time-discrete linear, time-invariant systems and deterministic signals in the time and frequency domain
- name essential properties of digital signals
- apply the discrete Fourier transform (DFT) and the fast Fourier transform (FFT), respectively
- state essential methods and design procedures for non-recursive (FIR) and recursive (IIR) filters as well as procedures for spectral analysis
- apply spectral analysis methods to concrete examples
- design a mathematical model in state space representation for simple technical systems
- simplify mathematical models by linearisation
- analyse the behaviour of linear and time-invariant dynamic systems with the help of state equations
- use design procedures to design state controls for single-variable systems

**Contents**

- Description of time-discrete signals and systems in the time domain
- Description in frequency domain: Fourier transformation, frequency response
- Sampling/reconstruction, periodic spectra, aliasing
- Discrete-time non-recursive (FIR) and recursive (IIR) filters, transfer function
- Spectral estimation for discrete-time signals
- Deriviation of LTI state equations
    - Mathematical modelling
    - Linearization around operating point
- Solution of the state equations, stability, controllability and observability
- Structure and design of linear state-space controllers
- Structure and design of Luenberger observer, separation principle
- Disturbance rejection

**Literature and other learning resources**

- Oppenheim, V.; Schafer, R. W.: Discrete-time Signal Processing, Prentice Hall, 3rd ed., 2010.
- Proakis, J.G; Manolakis, D.G.: Digital Signal Processing; Pearson, 4th ed., 2013.
- Hsu, H.P.: Schaum's Outline of Signals and Systems; 4th ed., McGraw-Hill, 4th ed., 2019.

- Lyons, R.G.: Understanding Digital Signal Processing; 3rd ed., Addison Wesley, 2010.
- Dorf, R. C.; Bishop, R. H.: Modern Control Systems. 13th ed., Pearson, 2017.
- Nise, N. S.: Control Systems Engineering. International Student Version. 6th ed., John Wiley & Sons, 2011.
- Billingsley, J: Essentials of Control Techniques and Theory. CRC Press, 2010.
- Zhou, K.; Doyle, J. C.; Glover, K.: Robust and Optimal Control, Prentice Hall, 1995.

| **Special notes** |
|---|
| |

# Core Elective 1

## Development Processes and Legal Basics

| Module Length | Regular Cycle | Workload |
|---|---|---|
| 1 Semester | Sommersemester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Responsible for the lecture:** Prof. Dr. Jean Meyer

**Lecturer(s):**

N.N.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Development Processes and Legal Basics | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

None

**Learning objectives**

The students

- name basic development models
- apply development models to the development of technical products
- state the legal framework of standardisation at European level as well as CE marking and patent law
- describe the legal significance of standards for product development
- list technical standards relevant to robotics
- describe methods of risk analysis and the associated obligations for robot manufacturers
- describe the steps for risk assessment of workplaces and the associated obligations for the employer
- list legal aspects of occupational safety, as well as aspects of quality management.

**Contents**

- Development processes
- Occupational Safety
- Overview of relevant standards
- Principles of CE marking
- Patent law
- Risk analysis and risk assessment
- Quality Management

**Literature and other learning resources**

- SCHNEIDER, André. Zertifizierung im Rahmen der CE-Kennzeichnung. Hüthig, 2008.
- KREY, Volker; KAPOOR, Arun. Praxisleitfaden Produktsicherheitsrecht: CE-Kennzeichung-Gefahrenanalyse-Betriebsanleitung-Konformitätserklärung-Produkthaftung-Fallbeispiele. Carl Hanser Verlag GmbH Co KG, 2014.

**Special notes**

## Module No. 21

## Control Systems

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Sommersemester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Bernhard Müller

**Lecturer(s):**

Prof. Dr. B. Müller, Prof. Dr. A. Ali

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Control Systems | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 4. Fachsemester)

| | |
|---|---|
| Provides the basis for module(s): | Actuators (29) |
| Builds up on module(s): | Systems Theory (14) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Systems Theory (14)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- name basic terminology of control engineering and describe mechanism of the feedback control
- explain static and dynamic behaviour of control-loop components, describe them in time and frequency domain and identify fundamental characteristics of important systems (P, I, D, first-order lag, second-order-lag etc. )
- explain the working principle of the classical PID control, describe characteristic features and properties of each controller component and select a suitable controller for a given application
- analyse control systems for stability, oscillations, steady-state accuracy and speed of response using open-loop frequency response and pole-zero maps
- build a simulation model for a simple control loop and execute a model-based controller design
- use heuristics and empirical methods to select suitable controller structure and adjust its parameters
- design a feedback controller for a single-input-single-output system using analytical using frequency response and pole-placement techniques

**Contents**

- Introduction
    - Basic terminology, plan of action, feedback control

- Behaviour of control system components
  - Deriving system equations
  - Description in time and frequency domain
  - Transfer function,
  - Modelling and simulation
- PID control
- Control loop analysis
  - Stability, speed of response, oscillation behaviour, steady-state accuracy
- Controller design
  - Empirical design methods
  - Model-based control design
  - Controller design in frequency domain (loop shaping)
  - Pole placement method / root locus.

**Literature and other learning resources**


- K. J. Åström and R. M. Murray, Feedback systems: an introduction for scientists and engineers. Princeton, NJ: Princeton University Press, 2009.
- K. Ogata, Modern Control Engineering, 5th ed. Upper Saddle River, NJ: Pearson Education, 2010.
- R. Dorf, R. Bishop, Modern Control Systems, 13th ed. Hoboken, NJ: Pearson Education, 2017.
- H. Unbehauen, Regelungstechnik I, 15th ed. Wiesbaden: Springer Vieweg, 2008.
- J. Lunze, Regelungstechnik 1, 12th ed. Berlin: Springer-Verlag, 2020.


**Special notes**

## Module No. 22

## Distributed Systems and Network Communication

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Markus Mathes

**Lecturer(s):**

Prof. Dr. M. Mathes, Prof. Dr. L. Eckert

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Distributed Systems and Network Communication | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 4th semester)

| | |
|---|---|
| Provides the basis for module(s): | None |
| Builds up on module(s): | Embedded Systems and Field Buses (17) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Embedded Systems and Field Buses (17)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- name different theoretical models for distributed systems, in particular the different types of transparency
- apply the architectural principles of distributed systems
- describe the special challenges regarding global time, global states and transactions
- develop a parallel algorithm in the Java programming language for a given task in a structured form
- use message- and memory-coupled techniques for programming distributed systems
- apply techniques for the scalability of distributed systems
- select techniques for load balancing, replication and caching
- define the basics of grid and cloud computing
- present network communication methods
- plan deployment concepts and adapt specific requirements accordingly
- set transmission parameters correctly

**Contents**

Distributed systems:

- Architecture of distributed systems, name services, global time, global state, transactions, CAP theorem.

- Client-server architectures, network communication and protocols for remote procedure call, remote method invocation
- Scalable software architectures, principles of load balancing, application of replication and caching techniques, cloud computing and technical administration

Network Communication:

- TCP-IP stack
- Osi-iso reference model
- Service-oriented architectures
- Cloud computing
- Distributed algorithms

**Literature and other learning resources**

- Stefan Tilkov und Martin Eigenbrodt: REST und HTTP: Entwicklung und Integration nach dem Architekturstil des
- Web. dpunkt Verlag, 2015.
- Christoph Meinel und Harald Sack: WWW: Kommunikation, Internetworking, Web-Technologien. Springer, 2004.
- Clay Breshears: The Art of Concurrency: A Thread Monkeys Guide to Writing Parallel Applications. OReilly, 2009.
- Wendell Odom: Cisco CCNA Routing und Switching ICND2 200-101: Das offizielle Handbuch zur erfolgreichen Zertifizierung; dpunkt.verlag GmbH 2014
- Comer, Douglas E.: Internetworking with TCP/IP, Vol.1: Principles, Protocols, and Architectures, Prentice Hall International 2000
- Douglas E. Comer: Computernetzwerke und Internets; Verlag Pearson Studium, Prentice Hall, 2000

**Special notes**

## Module No. 23

### Machine Learning

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Sommersemester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Rainer Herrler

**Lecturer(s):**

Prof. Dr. R. Herrler

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Machine Learning | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor’s programme Robotics (Core module, 4th semester)

| | |
|---|---|
| Provides the basis for module(s): | Core Elective 2 „Deep Learning“, „Mobile Robotics“ and „Humanoid and Service Robotics“ specialisation modules |
| Builds up on module(s): | Statistics and Sensor Data Fusion (13) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Statistics and Sensor Data Fusion (13)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- classify machine learning as a discipline in the subject area of artificial intelligence
- name areas of application of machine learning in engineering
- list relevant parameters for describing model quality
- state the differences between supervised and unsupervised learning
- select and apply basic machine learning algorithms according to the learning task at hand
- evaluate the success of a machine learning process using appropriate criteria and parameters
- describe the structure of neural networks and the course of the training process
- name different activation functions
- use relevant software tools to solve machine learning tasks
- name requirements for hardware products that arise in connection with machine learning tasks

**Contents**

- Conceptual classification of "machine learning" and differentiation from other sub-fields of artificial intelligence
- Methods of supervised and unsupervised learning

- Basics concepts of reinforcement learning
- Basic machine learning algorithms and their application, e.g. k-Means Clustering,
- DBScan, Gaussian Mixture Model, k-Nearest Neighbor, Naive Bayes Classification, Support Vector Machines (SVM), Decision Trees
- Silhouette Score and Silhoutte Graph
- Confusion Matrix
- Structure and functioning of neural networks including activation functions
- Selected software tools
- Hardware for ML applications

**Literature and other learning resources**


- ALPAYDIN, Ethem. Maschinelles Lernen. Walter de Gruyter GmbH & Co KG, 2019
- FROCHTE, Jörg. Maschinelles Lernen: Grundlagen und Algorithmen in Python. Carl Hanser Verlag GmbH Co KG, 2019
- ALPAYDIN, Ethem. Introduction to machine learning. MIT press, 2020.
- FORSYTH, David, Applied Machine Learning, Springer Nature, 2019


**Special notes**

# Module No. 24

## Robotics Lab 4

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>90 hrs self-directed study time | 5 |

**Responsible for module:** Prof. Dr. Jean Meyer

**Lecturer(s):**

Prof. Dr. M. Schmidt, Prof. Dr. R. Herrler, Prof. Dr. B. Müller

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Robotics Lab 4 | Seminar and lab course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 4. semester)

| | |
|---|---|
| Provides the basis for module(s): | Robotics Project (33) |
| Builds up on module(s): | Robotics Lab 3 (18) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Robotics Lab 1 (6), Robotics Lab 2 (12), Robotics Lab 3 (18)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Other type of assessment | --- | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students

- apply the theoretical knowledge from modules of the semester in practical course units and experiments
- select suitable methods from the lectures for conducting the practical experiments
- apply robotics-relevant software tools
- use software tools for the development and application of robots
- analyse processes and methods in the context of practical experiments
- plan experiments, carry them out and document the results in a scientific format
- interpret experimental results and draw conclusions from them with regard to the underlying influencing factors and cause-effect relationships

**Contents**

- Introduction to Linux and ROS:
  - Introduction to the ROS framework
  - Introduction to ROS Gazebo and rviz
  - Programming of a mobile platform with ROS
- Introduction to Machine Learning with Matlab
- Control Systems lab:
  Design, simulation and testing of conventional controllers

**Literature and other learning resources**

| |
|---|
| • Experimental instructions, lab manuals and supplementary documents on the FHWS eLearning system. |
| **Special notes** |
| |

## 3 Internship phase, 5th semester

| **Module No. 25** | | | |
|---|---|---|---|
| **Internship** | | | |
| **Module length** | **Regular Cycle** | **Workload** | **ECTS-Credit Points** |
| 1 Semester | Winter semester | Total: 750 hrs<br>700 hrs attendance time (industry)<br>50 hrs preparation for the industry internship | 25 |
| **Responsible for module:** Internship coordinator | | | |
| **Lecturer(s):** | | | |
| Not applicable | | | |
| **Associated class(es)** | | **Teaching and learning format** | **Language of instruction** |
| Not applicable | | Internship | Not applicable |
| **Applicability and study semester in accordance with the study and examination regulations** | | | |
| Bachelor's programme Robotics (Core module, 5th semester)<br><br>Provides the basis for module(s): Bachelor's Thesis (36)<br>Builds up on module(s): Modules of the basic study phase | | | |
| **Conditions of participation in accordance with study and examination regulations** | | | |
| Minimum of 90 ECTS-Points from successfully completed modules. | | | |
| **Recommended conditions of participation and prior knowledge** | | | |
| None | | | |
| **Examination type / Prerequisite for the award of credit points** | **Examination length** | **Examination language** | |
| Not applicable | Not applicable | Not applicable | |
| *Proof of successful completion of the internship by means of an internship certificate is required for the award of credit points.* | | | |
| **Learning objectives (after successful completion of the module)** | | | |
| Students transfer the engineering knowledge they have acquired by applying it in practice under the supervision of engineers. | | | |
| **Contents** | | | |
| The required contents of the practical phase are described in the internship guidelines of the degree programme. | | | |
| **Literature and other learning resources** | | | |
| | | | |
| **Special notes** | | | |
| | | | |

## Module No. 26

## General Elective

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Faculty of Applied Natural Sciences and Humanities

**Lecturer(s):**

All lecturers of general electives

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| 2 modules as selected by the student from the course catalogue for general elective modules (2 SWS each) | Seminar-like lecture, exercise course | English or foreign language |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 5th semester)

| | |
|---|---|
| Provides the basis for module(s): | None |
| Builds up on module(s): | None |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

None

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Dependent on the module chosen; see respective specifications | Dependent on the module chosen; see respective specifications | Dependent on the module chosen; see respective specifications |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published by the faculty of Applied Natural Sciences and Humanities (FANG).*

**Learning objectives (after successful completion of the module)**

The course-specific learning objectives are described on the website the faculty of Applied Natural Sciences and Humanities (see below).

**Contents**

- Impartment of general knowledge
- Honing key skills like presentation and communication skills
- Foreign languages
- The modules offered as well as the course descriptions can be found in the respective catalogues for general elective modules:
  - For Schweinfurt: http://fang.fhws.de/studium/allgemeinwissenschaftliche_wahlpflichtfaecher/angebote_in_schweinfurt/aktuelles_und_termine.html
  - For Würzburg: http://fang.fhws.de/studium/allgemeinwissenschaftliche_wahlpflichtfaecher/angebote_in_wuerzburg/aktuelles_und_termine.html

| Literature and other learning resources |
|---|
| • In accordance with description in the course catalogue; lecture notes may be available on the university´s e-learning site. |
| **Special notes** |
| • Specific online courses by the Virtual University of Bavaria are also available.<br>• Some courses include excursions and guest lectures. |

## 4 Subject- and Specialisation studies, 6th and 7th semester

### Module No. 27

### Core Elective 2A

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Dean of studies

**Lecturer(s):**

The lecturers can be found in the descriptions of the individual courses.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| See catalogue Core Electives 2 | Seminar-like lecture, exercise course | English |

*One of the courses from the catalogue specified in the curriculum for module 27 (Core Elective 2A) must be selected. The selected course must be different from the selection for module 28 (Core Elective 2B).*

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core elective, 6th semester)

| | |
|---|---|
| Provides the basis for module(s): | None |
| Builds up on module(s): | Modules of the basic study period (1st to 4th semester) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

The recommended conditions of participation and prior knowledge can be found in the descriptions of the individual courses.

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

In the core elective modules, students choose from a catalogue of courses in the fields of robotics according to their preferences and professional expectations. The course-related learning objectives can be found in the descriptions of the individual courses.

**Contents**

The contents can be found in the descriptions of the individual courses.

**Literature and other learning resources**

The literature references can be found in the descriptions of the individual courses.

**Special notes**

## Module No. 28

## Core Elective 2B

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Dean of studies

**Lecturer(s):**

The lecturers can be found in the descriptions of the individual courses.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| See catalogue Core Electives 2 | Seminar-like lecture, exercise course | English |

*One of the courses from the catalogue specified in the curriculum for module 28 (Core Elective 2B) must be selected. The selected course must be different from the selection for module 27 (Core Elective 2A).*

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core elective, 6th semester)

| | |
|---|---|
| Provides the basis for module(s): | None |
| Builds up on module(s): | Modules of the basic study period (1st to 4th semester) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

The recommended conditions of participation and prior knowledge can be found in the descriptions of the individual courses.

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

In the core elective modules, students choose from a catalogue of courses in the fields of robotics according to their preferences and professional expectations. The course-related learning objectives can be found in the descriptions of the individual courses.

**Contents**

The contents can be found in the descriptions of the individual courses.

**Literature and other learning resources**

The literature references can be found in the descriptions of the individual courses.

**Special notes**

## Catalogue Core Electives 2

Catalogue of courses for modules 27 (Core Elective 2A) and 28 (Core Elective 2B). The courses are usually offered in the summer semester.

| Title of the lecture | Responsible for the lecture |
|---|---|
| Deep Learning | Prof. Dr. Rainer Herrler |
| 3D Machine Vision | Prof. Dr. Volker Willert |
| Advanced Kinematics | Prof. Dr. Jean Meyer |
| Robot Programming | Prof. Dr. Tobias Kaupp |

## Core Elective 2

## Deep Learning

| Module length | Regular Cycle | Workload |
|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Responsible for the lecture:** Prof. Dr. Rainer Herrler

**Lecturer(s):**

Prof. Dr. R. Herrler

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Deep Learning | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Machine Learning (23)

**Learning objectives**

The students

- describe the structure of neural networks and the function of the individual network elements
- demonstrate the learning process in a neural network at node level
- list different network structures as well as corresponding application examples
- describe the algorithms of forward and backward propagation
- describe the application of neural networks in the context of image recognition
- list different types of neural networks
- assess the suitability of neural networks with regard to the data basis and the desired result
- name application possibilities and application limits of transfer learning
- apply transfer learning to simple problems with the help of software tools
- use software tools to develop and apply neural networks
- define requirements for the necessary hardware in the context of deep learning.

**Contents**

- Structure and function of neural networks
- Classification of Deep Neural Networks (DNNs)
- Image recognition with DNN
- Forward Propagation and Backward Propagation
- Selected types of neural networks, e.g. CNN, RNN, LSTM, DAG
- Transfer learning
- Analysis and optimisation of neural networks
- Software tools for Deep Learning applications
- Deep reinforcement learning
- Hardware for Deep Learning applications

**Literature and other learning resources**

- GOODFELLOW, Ian; BENGIO, Yoshua; COURVILLE, Aaron. Deep learning. MIT press, 2016
- OSINGA, Douwe. Deep Learning Cookbook: Practical Recipes to Get Started Quickly. " O'Reilly Media, Inc.", 2018.
- RASHID, Tariq. Neuronale Netze selbst programmieren: ein verständlicher Einstieg mit Python. O'Reilly, 2017.

**Special notes**

## Core Elective 2

## 3D Machine Vision

| Module length | Regular Cycle | Workload |
|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Responsible for the lecture:** Prof. Dr. Volker Willert

**Lecturer(s):**

Prof. Dr. V. Willert

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| 3D Machine Vision | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Image Processing (16)

**Learning objectives**

The students

- name different 3D imaging techniques
- describe the functional principles of 3D imaging techniques
- list application-related advantages and disadvantages of 3D imaging techniques
- state the camera calibration procedure
- name relevant calibration parameters
- list aspects of storing and processing point clouds
- use point clouds to determine the position and pose of objects
- evaluate application limits of methods for position determination depending on the data basis
- name basic functions of the OpenCV library for 3D machine vision applications name the tools of the OpenCV library for 3D machine vision applications
- select tools from the OpenCV library for robotics-relevant tasks

**Contents**

- 3D camera systems and 3D reconstruction:
  - TOF
  - Stereo
  - Strip light projection
- Camera calibration
- Structure from motion (SfM)
- 3D position and pose estimation
- Point clouds
- Introduction to OpenCV (e.g. in Matlab)
- Application examples: 3D object recognition, gesture recognition, object tracking

**Literature and other learning resources**

- DAVIES, E. Roy. Computer vision: principles, algorithms, applications, learning. Academic Press, 2017
- SÜẞE, Herbert; RODNER, Erik. Bildverarbeitung und Objekterkennung. Springer Fachmedien Wiesbaden, 2014.
- JOSHI, Prateek; ESCRIVÁ, David Millán; GODOY, Vinicius. OpenCV By Example. Packt Publishing Ltd, 2016.
- CORKE, Peter. Robotics, vision and control: fundamental algorithms in MATLAB® second, completely revised. Springer, 2017

| **Special notes** |
|---|
| |

## Core Elective 2

## Advanced Kinematics

| Module Length | Regular Cycle | Workload |
|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Responsible for the lecture:** Prof. Dr. Jean Meyer

**Lecturer(s):**

N.N.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Advanced Kinematics | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Robot Mechanics 1 (3) and Robot Mechanics 2 (9)

**Learning objectives**

The students

- list different parallel kinematics
- name application-specific advantages and disadvantages of parallel kinematics
- develop the forward and backward kinematics of complex parallel kinematics
- state lightweight construction potentials for robot kinematics
- quantify weight savings through lightweight construction measures for selected kinematics
- describe essential elements of soft kinematics and their function
- examine control-specific aspects of soft actuators

**Contents**

Parallel kinematics:

- Parallel platforms: Elements and structure
- Dynamics of parallel platforms
- Forward and inverse kinematics

Lightweight construction:

- Importance of lightweight construction for robotics
- Lightweight materials
- Lightweight construction
- Lightweight production

Soft Robotics:

- Basics of pneumatic actuators
- Control of pneumatic actuators
- Electroactive polymers for actuators

**Literature and other learning resources**

- VERL, Alexander, et al. Soft Robotics. Berlin, Germany:: Springer, 2015.
- LIU, Xin-Jun; WANG, Jinsong. Parallel Kinematics – Type, Kinematics and Optimal Design, Springer, Berlin, Germany, 2014
- STAICU, Stefan. Dynamics of Parallel Robots. Springer International Publishing, 2019.

**Special notes**

## Core Elective 2

## Robot Programming

| Module length | Regular Cycle | Workload |
|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Responsible for the lecture:** Prof. Dr. Tobias Kaupp

**Lecturer(s):**

N.N.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Robot Programming | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Programming 1 (5) and Programming 2 (11)

**Learning objectives**

The students

- name selected proprietary robot programming languages
- state different types of robot programming
- develop simple programs for stationary industrial robots using blending and including sensors information
- use graphical programming environments to create programs
- design ROS programs for mobile robots
- describe information processing in ROS
- list relevant tools and libraries for use in ROS
- describe the procedure for developing simulations in Gazebo
- name the application possibilities of ROS-Industrial and list application examples

**Contents**

Programming of industrial robots:

- Proprietary and standardized robot programming languages
- Fundamentals of path control
- Types of programming
- Structure of robot programs
- Access of input/output-interfaces
- Integration and utilization of sensor data
- Blending
- Application of motion modes T1/T2/Auto
- Graphical programming

Robot Operating System (ROS):

- Architecture and working environment
- Robot Software Architectures
- Relevant tools and libraries
- ROS-Industrial
- Simulation in Gazebo and application examples

**Literature and other learning resources**

- QUIGLEY, Morgan; GERKEY, Brian; SMART, William D. Programming Robots with ROS: a practical introduction to the Robot Operating System. " O'Reilly Media, Inc.", 2015.
- MAHTANI, Anil, et al. Effective robotics programming with ROS. Packt Publishing Ltd, 2016.
- PIRES, J. Norberto. Industrial robots programming: building applications for the factories of the future. Springer Science & Business Media, 2007.


| **Special notes** |
| --- |
| |

## Module No. 29

## Actuators

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 5 |

**Responsible for module:** Prof. Dr. Bernhard Müller

**Lecturer(s):**
Prof. Dr. B. Müller

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Actuators | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 6th semester)

| | |
|---|---|
| Provides the basis for module(s): | None |
| Builds up on module(s): | Control Systems (21) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Control Systems (21)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Written exam | 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The students
- state the physical principles, structure and function of electric drives
- develop the mathematical relationships for describing the functional chains for electric motors
- design electric drive systems on the basis of technical requirements
- analyse the technical requirements of controlled drives
- develop drive systems based on the components
- plan the necessary work steps for the development of drives in a targeted manner, carry them out practically and critically evaluate the results

**Contents**

- Magnetic circuits
- Operating principles of electromechanical energy converters and overview about design variants
- Modelling the mechanics of drive systems
- DC motors
  - Construction
  - Mathematical modelling
  - Stationary operating behavior

- Control of electrical drives
  - Fundamentals of power electronics
  - Cascaded feedback-control structure
  - Design of current, speed and position controllers
  - Constraints in practice
- Permanent-magnet synchronous motors
  - Construction
  - Mathematical modelling
  - Space vectors and field-oriented control

**Literature and other learning resources**


- Specovius, Joachim: Grundkurs Leistungselektronik, Vieweg+Teubner, 2011
- Schröder, Dirk: Elektrische Antriebe - Grundlagen, 5. Auflage, Springer, 2013
- Schröder, Dirk: Elektrische Antriebe - Regelung von Antriebssystemen, 3. Auflage, Springer, 2009
- Hughes: Electric Motors and Drives: Fundamentals, Types and Applications, Newens, 4th ed., 2013
- Mohan et al.: Power Electronics, John Wiley & Sons, 3rd. ed., 2002
- Teigelkötter, Johannes: Energieeffiziente elektrische Antriebe, Vieweg+Teubner, 2013


**Special notes**

## Specialisation „Industrial Robotics“

| Industrial Robotics | | | |
|---|---|---|---|
| **Module length** | **Regular Cycle** | **Workload** | **ECTS-Credit Points** |
| 2 Semester | Sommersemester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 15 |
| **Responsible for specialisation:** Prof. Dr. Jean Meyer | | | |
| **Lecturer(s):** | | | |
| The lecturers can be found in the descriptions of the individual courses. | | | |
| **Associated class(es)** | **Teaching and learning format** | **Language of instruction** | |
| Dynamics of industrial robots (4 SWS) | Seminar-like lecture, exercise course | English | |
| Automation and production technology (4 SWS) | Seminar-like lecture, exercise course | English | |
| Collaborative robotics (4 SWS) | Seminar-like lecture, exercise course | English | |
| **Applicability and study semester in accordance with the study and examination regulations** | | | |
| Bachelor’s programme Robotics (Specialisation module, 6th and 7th semester) | | | |
| **Conditions of participation in accordance with study and examination regulations** | | | |
| None | | | |
| **Recommended conditions of participation and prior knowledge** | | | |
| Basic study phase modules (1st to 4th semester) | | | |
| **Examination type / Prerequisite for the award of credit points** | **Examination length** | **Examination language** | |
| 3 x Written exam | 3 x 90 to 120 min | English | |
| *The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.* | | | |
| **Learning objectives (after successful completion of the module)** | | | |
| The learning objectives can be found in the descriptions of the individual courses. | | | |
| **Contents** | | | |
| The contents can be found in the descriptions of the individual courses. | | | |
| **Literature and other learning resources** | | | |
| The literature references can be found in the descriptions of the individual courses. | | | |
| **Special notes** | | | |
| | | | |

## Module No. 30 – Specialisation „Industrial Robotics"

## Dynamics of industrial robots

| Module Length | Regular Cycle | Workload |
|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Responsible for the lecture:** Prof. Dr. Jean Meyer

**Lecturer(s):**

N.N.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Dynamics of industrial robots | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Robot Mechanics 1 (3) and Robot Mechanics 2 (9)

**Learning objectives**

The students

- use the Jacobi matrix to describe the speed of the kinematic chain
- use the Jacobi matrix to describe forces and moments
- describe force control in a cobot
- use the Newton-Euler and Lagrange equations to describe accelerated motion
- describe path planning for industrial robots with up to 6 axes
- recognise singularities and describe possible solutions to avoid them

**Contents**

- Speed and acceleration of the kinematic chain
- Direct and inverse kinematics of complex industrial robots
- Force control
- Newton-Euler and Lagrange equation
- Jacobi matrix
- Singularities
- Path planning

**Literature and other learning resources**

- MARECZEK, Jörg Grundlagen der Roboter-Manipulatoren–Band 1: Modellbildung von Kinematik und Dynamik, Springer, Berlin, 2020
- MARECZEK, Jörg. Grundlagen der Roboter-Manipulatoren–Band 2: Pfad-und Bahnplanung, Antriebsauslegung, Regelung, Springer, Berlin, 2020.

**Special notes**

## Module No. 31 – Specialisation „Industrial Robotics“

## Automation and production technology

| Module length | Regular Cycle | Workload |
|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Verantwortlich für die Lehrveranstaltung:** Prof. Dr. Jean Meyer

**Lecturer(s):**

N.N.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Automation and production technology | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Robot Mechanics 1 (3) and Robot Mechanics 2 (9)

**Learning objectives**

The students

- name elements of automation technology
- design simple automation processes with electromechanical actuators
- select components for simple automated production processes
- list different gripper techniques
- select grippers for specific tasks
- calculate parameters relevant for the design of grippers
- describe the integration of PLCs in production processes
- name relevant protocols and interfaces in industrial communication
- describe the possible applications of IoT technologies in the industrial environment

**Contents**

- Selection and design of grippers
- Planning of automated production lines
- Handling and processing with industrial robots
- Assembly processes
- PLC technology
- Industrial communication
- IoT in the industrial environment

**Literature and other learning resources**

- WELLENREUTHER, Günter; ZASTROW, Dieter. Automatisieren mit SPS: Theorie und Praxis. Springer-Verlag, 2005
- HEIMBOLD, Tilo. Einführung in die Automatisierungstechnik: Automatisierungssysteme, Komponenten, Projektierung und Planung. Carl Hanser Verlag GmbH Co KG, 2014

**Special notes**

## Module No. 32 – Specialisation „Industrial Robotics“

## Collaborative Robotics

| Module length | Regular Cycle | Workload |
|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Verantwortlich für die Lehrveranstaltung:** Prof. Dr. Jean Meyer

**Lecturer(s):**

N.N.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Collaborative Robotics | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Robot Mechanics 1 (3) and Robot Mechanics 2 (9)

**Learning objectives**

The students

- name safety-relevant standards in dealing with collaborative robots
- list types of human-robot collaboration
- assess the automation potential through the use of collaborative robots
- select safety-relevant components to complement collaborative workplaces
- evaluate the design of collaborative workstations from a process and safety point of view
- describe the sensors for measuring forces and moments and their installation in collaborative robots
- describe methods of electromechanical force control
- define technical limits of force control including kinematic aspects

**Contents**

- Application areas and potentials of collaborative robots
- Types of human-robot collaboration
- Safety-relevant components for collaborative workplaces
- Grippers for HRC applications
- Legal framework (norms and standards)
- Structure and design of collaborative workplaces
- Torque/force sensors in collaborative robots
- Control concepts for force control

**Literature and other learning resources**

- FRANKE, Jörg (Hg.). Handbuch Mensch-Roboter-Kollaboration. Carl Hanser Verlag GmbH Co KG, 2019
- BUXBAUM, Hans-Jürgen, Mensch-Roboter-Kollaboration, Springer Gabler, Wiesbaden, 2020

**Special notes**

## Specialisation „Mobile Robotics“

| **Mobile Robotics** | | | |
|---|---|---|---|
| **Module length** | **Regular Cycle** | **Workload** | **ECTS-Credit Points** |
| 2 Semester | Summer semester and winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 15 |
| **Responsible for specialisation:** Prof. Dr. Tobias Kaupp | | | |
| **Lecturer(s):** | | | |
| The lecturers can be found in the descriptions of the individual courses. | | | |

| **Associated class(es)** | **Teaching and learning format** | **Language of instruction** |
|---|---|---|
| Localisation and mapping (4 SWS) | Seminar-like lecture, exercise course | English |
| Aerial drones (4 SWS) | Seminar-like lecture, exercise course | English |
| Navigation and mobile platforms (4 SWS) | Seminar-like lecture, exercise course | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor’s programme Robotics (Specialisation modules, 6th and 7th semester)

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Basic study phase modules (1st to 4th semester)

| **Examination type / Prerequisite for the award of credit points** | **Examination length** | **Examination language** |
|---|---|---|
| 3 x Written exam | 3 x 90 to 120 min | English |

*The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.*

**Learning objectives (after successful completion of the module)**

The learning objectives can be found in the descriptions of the individual courses.

**Contents**

The contents can be found in the descriptions of the individual courses.

**Literature and other learning resources**

The literature references can be found in the descriptions of the individual courses.

**Special notes**

# Module No. 30 – Specialisation „Mobile Robotics“

## Localisation and mapping

| Module Length | Regular Cycle | Workload |
|---|---|---|
| 1 Semester | Sommersemester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Responsible for the lecture:** Prof. Dr. Tobias Kaupp

**Lecturer(s):**

N.N.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Localisation and mapping | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Sensors and Metrology (10), Statistics and Sensor Data Fusion (13)

**Learning objectives**

The students

- describe the function of sensors for perception in in- and outdoor applications
- name sensor- and application-specific challenges that are relevant for perception
- distinguish between methods for landmark and path marker detection
- assess the accuracy and application limits of global localisation methods
- describe the particle filter and Kalman filter in the context of localisation
- enumerate environment models
- use the concept of odometry for localisation
- list the challenges associated with the SLAM algorithm
- implement the SLAM algorithm in a programming language

**Contents**

- Perception in indoor and outdoor areas
- Landmark and path marker recognition
- GPS/IMU-based localisation
- Particle filter and Kalman filter in localisation
- Environment models
- Odometry in the context of mobile platforms
- SLAM

**Literature and other learning resources**

- SIEGWART, Roland; NOURBAKHSH, Illah Reza; SCARAMUZZA, Davide. *Introduction to autonomous mobile robots*. MIT press, 2011.
- THRUN, S.; Burgard, W.; Fox, D., Probabilistic Robotics, MIT Press, 2005
- KUDRIASHOV, Andrii, et al. SLAM Techniques Application for Mobile Robot in Rough Terrain.
- NÜCHTER, Andreas. 3D robotic mapping: the simultaneous localization and mapping problem with six degrees of freedom. Springer, 2008.

**Special notes**

# Module No. 31 – Specialisation „Mobile Robotics“

## Aerial drones

| Module length | Regular Cycle | Workload |
|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Responsible for the lecture:** Prof. Dr. Tobias Kaupp

**Lecturer(s):**

N.N.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Aerial drones | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Sensors and Metrology (10)

**Learning objectives**

The students

- name relevant sensors for flight control of commercial and non-commercial drones
- describe the concept of visual odometry
- define components and techniques for flight and attitude control
- plan application-specific power requirements of drones
- specify aerodynamic aspects of drones
- list drone platforms
- list components for energy supply and define them in terms of power and capacity
- describe common methods for data transmission in exchange with ground-based stations
- select electric drives for drones
- list relevant legal regulations for the operation of drones
- state which authorities must be contacted for the operation of drones requiring a licence

**Contents**

- Sensors for flight control
- Visual odometry
- Flight / attitude control technology
- Power requirements and power limits
- Aerodynamics of aircraft and drones
- Drone platforms
- Power supply
- Data transmission
- Electric drives for drones
- Legal aspects

**Literature and other learning resources**

- NONAMI, Kenzo, et al. Autonomous flying robots: unmanned aerial vehicles and micro aerial vehicles. Springer Science & Business Media, 2010.

**Special notes**

## Module No. 32 – Specialisation „Mobile Robotics“

## Navigation and mobile platforms

| **Module length** | **Regular Cycle** | **Workload** |
|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Responsible for the lecture:** Prof. Dr. Tobias Kaupp

**Lecturer(s):**

N.N.

| **Associated class(es)** | **Teaching and learning format** | **Language of instruction** |
|---|---|---|
| Navigation and mobile Plattformen | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Robot Mechanics 2 (9)

**Learning objectives**

The students

- describe the construction of land-based as well as water and underwater platforms for mobile robots
- name steering types of wheel-driven robots
- describe the kinematics of land-based robots
- evaluate approaches for local and global path planning
- describe methods for obstacle avoidance
- handle approaches for obstacle detection and obstacle avoidance
- carry out map-based navigation according to different target criteria on the basis of examples

**Contents**

- Land-based, water and underwater platforms for mobile robots
- Steering of wheel-driven platforms
- Types of locomotion
- Kinematics of land-based robots
- Path planning with path map, cell map and potential field methods
- Obstacle avoidance
- Navigation architectures

**Literature and other learning resources**

- ANTONELLI, Gianluca; ANTONELLI, G. Underwater robots. Switzerland: Springer International Publishing, 2014.
- CHATTERJEE, Amitava; RAKSHIT, Anjan; SINGH, N. Nirmal. Vision based autonomous robot navigation: algorithms and implementations. Springer, 2012.

**Special notes**

## Specialisation Humanoid and Service Robotics

| Humanoid and Service Robotics | | | |
|---|---|---|---|
| **Module length** | **Regular Cycle** | **Workload** | **ECTS-Credit Points** |
| 2 Semester | Summer and winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation | 15 |
| **Responsible for specialisation:** Prof. Dr. Marco Schmidt | | | |
| **Lecturer(s):** | | | |
| The lecturers can be found in the descriptions of the individual courses. | | | |

| **Associated class(es)** | **Teaching and learning format** | **Language of instruction** |
|---|---|---|
| Human Robot Interaction (HRI) I (4 SWS) | Seminar-like lecture, exercise course | English |
| Speech recognition and speech synthesis (4 SWS) | Seminar-like lecture, exercise course | English |
| Human Robot Interaction (HRI) II (4 SWS) | Seminar-like lecture, exercise course | English |

| **Applicability and study semester in accordance with the study and examination regulations** |
|---|
| Bachelor’s programme Robotics (Specialisation modules, 6th and 7th semester) |
| **Conditions of participation in accordance with study and examination regulations** |
| None |
| **Recommended conditions of participation and prior knowledge** |
| Basic study phase modules (1st to 4th semester) |

| **Examination type / Prerequisite for the award of credit points** | **Examination length** | **Examination language** |
|---|---|---|
| 3 x Written exam | 3 x 90 to 120 min | English |
| *The duration of the examination, the scope of the examination and other examination conditions (e.g. permitted auxiliary means) are defined in the examination conditions. These are published on the faculty intranet at the beginning of each semester.* | | |

| **Learning objectives (after successful completion of the module)** |
|---|
| The learning objectives can be found in the descriptions of the individual courses. |
| **Contents** |
| The contents can be found in the descriptions of the individual courses. |
| **Literature and other learning resources** |
| The literature references can be found in the descriptions of the individual courses. |
| **Special notes** |
| |

# Module No. 30 – Specialisation „Humanoid and Service Robotics"

## Human Robot Interaction (HRI) I

| Module Length | Regular Cycle | Workload |
| --- | --- | --- |
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Responsible for the lecture:** Prof. Dr. Marco Schmidt

**Lecturer(s):**

N.N.

| Associated class(es) | Teaching and learning format | Language of instruction |
| --- | --- | --- |
| Human Robot Interaction (HRI) I | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Robot Mechanics 2 (9), Sensors and Metrology (10)

**Learning objectives**

The students

- give examples for the application of service robots
- list criteria that are important for the acceptance of service robots
- select human-robot interfaces according to context
- describe approaches to multimodal communication
- assess dialogue designs using the example of a humanoid robot
- describe socially compatible design principles
- name examples of application and possibilities of visual recognition procedures in the context of service robotics

**Contents**

- Application of service robots, e.g. in care, in the home, in teaching.
- Acceptance of service robots
- Human-robot interfaces
- Multimodal communication
- Dialogue design
- Socially compatible design of robots and social HRI
- Application examples for visual recognition of gestures, attention status, state of mind/facial expression, age

**Literature and other learning resources**

- SIEGWART, Roland; NOURBAKHSH, Illah Reza; SCARAMUZZA, Davide. Introduction to autonomous mobile robots. MIT press, 2011
- BARTNECK, Christoph, et al. Mensch-Roboter-Interaktion: Eine Einführung. Carl Hanser Verlag GmbH Co KG, 2020
- MAHAPATRA, Abhijit; ROY, Shibendu Shekhar; PRATIHAR, Dilip Kumar. Multi-body Dynamic Modeling of Multi-legged Robots. Springer Nature, 2020

**Special notes**

## Module No. 31 – Specialisation „Humanoid and Service Robotics“

## Speech recognition and synthesis

| Module length | Regular Cycle | Workload |
|---|---|---|
| 1 Semester | Summer semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Responsible for the lecture:** Prof. Dr. Marco Schmidt

**Lecturer(s):**

N.N.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Speech recognition and synthesis | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Machine Learning (23)

**Learning objectives**

The students

- name methods for processing audio data and their function
- describe methods for speech recognition
- state aspects of psychoacoustics
- name audio codecs and their advantages and disadvantages
- select Deep Learning based approaches for selected challenges related to speech and text processing
- describe methods for audio data compression
- state fields of application for verbal communication systems and their application limits
- apply methods of speech synthesis
- discuss sentence formation models using examples

**Contents**

Speech recognition:

- Methods of audio data processing (spectral analysis, noise reduction, feature extraction, etc.)
- Models and methods of speech recognition (Hidden Markov Models, Deep Neuronal Networks [DNN])
- Psychoacoustics
- Audio codecs
- Audio data compression
- Selected DL applications for speech and text processing, e.g. text classification, sentiment analysis, Word2vec

Speech synthesis:

- Application fields of verbal communicating systems ("speaking systems")
- Methods of speech synthesis:
    - Articulatory synthesis
    - Parametric synthesis
- Linguistic morphology - structure of words and inflectional forms
- Generative grammar - models of sentence formation

**Literature and other learning resources**


- PFISTER, Beat; KAUFMANN, Tobias. Sprachverarbeitung. Springer Berlin Heidelberg, 2008
- YU, Dong; DENG, Li. AUTOMATIC SPEECH RECOGNITION. Springer london limited, 2016

- BARTNECK, Christoph, et al. Mensch-Roboter-Interaktion: Eine Einführung. Carl Hanser Verlag GmbH Co KG, 2020

| **Special notes** |
|---|
| |

## Module No. 32 – Specialisation „Humanoid and Service Robotics"

## Human Robot Interaction (HRI) II

| Module Length | Regular Cycle | Workload |
|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>60 hrs self-directed study time<br>30 hrs exam preparation |

**Responsible for the lecture:** Prof. Dr. Marco Schmidt

**Lecturer(s):**

N.N.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Human Robot Interaction (HRI) II | Seminar-like lecture, exercise course | English |

**Recommended conditions of participation and prior knowledge**

Robot Mechanics 2 (9), Control Systems (21), Machine Learning (23)

**Learning objectives**

The students

- name methods of bionic optimisation
- list examples of bionically optimised/inspired elements in robotics
- represent parts of the human locomotion system as a kinematic model
- describe the structure of 2-legged and multi-legged platforms
- formulate requirements for the actuators of legged platforms
- differentiate modes of legged locomotion
- formulate requirements for the control technology for legged robots on the basis of the kinematics and the modes of locomotion
- develop kinematic models for legged platforms
- describe human-inspired learning and human transfer learning using the example of humanoid robots
- describe the use of reinforcement learning to develop movement patterns for locomotion of legged robots

**Contents**

- Methods of bionic optimisation
- Selected examples of applied bionics in robotics
- Anthropomorphic design of robots
- 2- and multi-legged platforms
- Modes of legged locomotion (walking, running, jumping)
- Kinematic description of legged platforms
- Design, elements and structure of legged kinematics
- Human-inspired motion and human transfer learning
- Reinforcement learning in the context of legged locomotion

**Literature and other learning resources**

- KAJITA, Shuuji, et al. Introduction to humanoid robotics. Springer Berlin Heidelberg, 2014.
- HARADA, Kensuke; YOSHIDA, Eiichi; YOKOI, Kazuhito (Hg.). Motion planning for humanoid robots. Springer Science & Business Media, 2010
- GOSWAMI, Ambarish; VADAKKEPAT, Prahlad (Hg.). Humanoid robotics: a reference. Netherlands: Springer, 2019.

**Special notes**

## Module No. 33

## Robotics Project

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 2 Semester | Summer and winter semester | Total: 300 hrs<br>150 hrs attendance time (10 SWS)<br>150 hrs self-directed study time | 10 |

**Responsible for module:** Prof. Dr. Jean Meyer

**Lecturer(s):**

Professors of the Faculty of Electrical Engineering, Mechanical Engineering, Applied Natural and Human Sciences and Computer Science and teaching assistants

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Robotics Project | Seminar, Projekt | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 6th and 7th Semester)

| | |
|---|---|
| Provides the basis for module(s): | None |
| Builds up on module(s): | Robotics Lab 1, 2, 3 and 4 (6, 12, 18, 24) |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Robotics Lab 1, 2, 3 and 4 (6, 12, 18, 24)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Other type of examination in the form of a project work according to §7 study and examination regulations (SPO) (consisting of a documentation and personal presentation) | During the 6th and 7th semester | English |

*The successful completion of the project, the preparation of the project documentation and the presentation within the framework of a final presentation are prerequisites for the award of credit points.*

**Learning objectives (after successful completion of the module)**

The students

- solve a project task either with a scientific character or with concrete practical relevance
- schedule the sequence of the individual realisation steps in the form of a timetable
- monitor the progress of the project
- include the financial framework conditions in the planning
- document the project including the relevant intermediate steps in the form of a project thesis
- defend the project work within the framework of a professional presentation with subsequent discussion

**Contents**

In the robotics project, students are given a robotics-specific development task to implement in small groups. The topics of the projects are individually defined and professionally supervised.

In the project, the students apply the theoretical knowledge they have gained in previous courses. In addition, they expand their extracurricular competences in the following areas:

- Project management
- documentation
- teamwork

| |
|---|
| • presentation techniques. |
| **Literature and other learning resources** |
| Learning resources on the FHWS eLearning. |
| **Special notes** |
| |

## Module No. 34

## Value Seminar

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 90 hrs<br>30 hrs attendance time (2 SWS)<br>60 hrs self-directed study time | 3 |

**Responsible for module:** Prof. Dr. Jean Meyer

**Lecturer(s):**

N.N.

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Value Seminar | Seminar | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 7th semester)

| | |
|---|---|
| Provides the basis for module(s): | None |
| Builds up on module(s): | None |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

Machine Learning (23)

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Other type of examination in the form of a presentation | During the 7th semester | English |

*The successful presentation is a prerequisite for the award of credit points.*

**Learning objectives (after successful completion of the module)**

The students

- recognise and evaluate potential ethical conflicts arising from the use of robots and artificial intelligence
- name conflicts that arise from the economic competition between robots and human labour.
- describe aspects of data protection in the context of the application of robots and AI by governmental organisations
- formulate the risks of highly developed AI

**Contents**

Discussion and reflection of issues from the fields of robotics and AI in the context of ethical aspects and sustainability.

**Literature and other learning resources**

- BARTNECK, Christoph, et al. Ethik in KI und Robotik. Carl Hanser Verlag GmbH Co KG, 2019
- RATH, Matthias; KROTZ, Friedrich; KARMASIN, Matthias. Maschinenethik. Springer Fachmedien Wiesbaden, 2019

**Special notes**

## Module No. 35

## Business Development and Entrepreneurship

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 150 hrs<br>60 hrs attendance time (4 SWS)<br>90 hrs self-directed study time | 5 |

**Responsible for module:** Prof. Dr. Volker Bräutigam

**Lecturer(s):**
Prof. Dr. V. Bräutigam

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Business Development and Entrepreneurship | Seminar | English |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor’s programme Robotics (Core module, 7th semester)

| | |
|---|---|
| Provides the basis for module(s): | None |
| Builds up on module(s): | None |

**Conditions of participation in accordance with study and examination regulations**

None

**Recommended conditions of participation and prior knowledge**

None

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Other type of examination in the form of a portfolio §7 SPO | During the 7th semester | English |

*The successful preparation of the portfolio is a prerequisite for the award of credit points.*

**Learning objectives (after successful completion of the module)**

The students
- use professional skills in building up a new business model and discuss an existing one, possibly their own, as a basis for founding new companies or innovating existing ones
- apply methodical knowledge about entrepreneurial thinking and acting, business models, presentation techniques, team building measures, communication channels (e.g. interview situation, Lego Serious Play), market research tools
- plan the necessary steps in founding a new start-up with e.g. an overview of government funding opportunities, personal financial security, patent rights, key figures and business plan
- apply interdisciplinary skills such as intercultural competences, personality building measures according to the requirements of the VUCA world, leadership responsibility and resilience.

**Contents**

The seminar provides knowledge about the design, structure and use of different business models. In addition to the business idea, the development and operation of a business model requires a suitable team, special forms of fundraising, special forms of presentation and special features of the business plan. This is consolidated in a practice-oriented manner through the use of a business game at the end of the semester and tested "gamified" on the market.
In addition, it is essential to centrally develop the personality of the founders in order to achieve a holistic, competence-oriented entrepreneurship education.

Optional: Elaboration of the learning outcomes using the example of an own business idea in a technological environment, especially robotics.

**Literature and other learning resources**


- Osterwalder, Alexander; Pigneur, Yves (2010): Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers. Wiley Verlag
- Osterwalder, Alexander; Pigneur, Yves et al. (2014): Value Proposition Design: How to create Products and Services Customers Want (Strategyzers). Wiley Verlag
- Bijedic, Teita (2013): Entwicklung unternehmerischer Persönlichkeit im Rahmen einer Entrepreneurship Education. Hampp Verlag
- Ries, Eric (2011): The Lean Startup: How Constant Innovation Creates Radically Successful Businesses. Portfolio Pingu-in.


**Special notes**

## Module No. 36

## Bachelor's Thesis

| Module length | Regular Cycle | Workload | ECTS-Credit Points |
|---|---|---|---|
| 1 Semester | Winter semester | Total: 360 hrs<br>Attendance time at the FHWS (discussion with supervisor) ca. 6 hrs<br>354 hrs self-directed study time | 12 |

**Responsible for module:** Dean of studies

**Lecturer(s):**

Supervisor (examiner) appointed by the examination committee (examiner)

| Associated class(es) | Teaching and learning format | Language of instruction |
|---|---|---|
| Not applicable | Not applicable | Not applicable |

**Applicability and study semester in accordance with the study and examination regulations**

Bachelor's programme Robotics (Core module, 7th semester)

| | |
|---|---|
| Provides the basis for module(s): | None |
| Builds up on module(s): | None |

**Conditions of participation in accordance with study and examination regulations**

- Minimum of 150 ECTS-Points from successfully completed modules
- Internship (25) completed successfully

**Recommended conditions of participation and prior knowledge**

Learning objectives of all the degree programme modules achieved

| Examination type / Prerequisite for the award of credit points | Examination length | Examination language |
|---|---|---|
| Bachelor's thesis according to §8 study and examination reulations (SPO) | Completion period if completed in one continuous period, generally 10 weeks (see Special Notes for further details) | English |

*Successful completion of the Bachelor's thesis is a prerequisite for the award of credit points.*

**Learning objectives (after successful completion of the module)**

The students

- apply their subject and methodological knowledge independently and across subjects/modules to a problem from the subject area of the degree programme
- develop an engineering solution on a scientific basis
- assess the impact of engineering solutions in the social and ecological environment
- use professional ethical principles and standards as a basis for their actions
- critically evaluate their existing knowledge
- recognise missing knowledge and competence deficits
- expand their existing knowledge on their own responsibility
- critically reflect on their own work
- apply project management methods to achieve desired goals in limited time and with limited resources and budgets
- fit into the social environment of e.g. a company
- present their results and their approach in a comprehensible way and according to the principles of scientific work in a written technical report

**Contents**

Independent solution of an engineering task from the subject area of the degree programme on a scientific basis.

**Literature and other learning resources**

- Relevant literature in accordance with the topic of the Bachelor's thesis
- Balzert et al.: Wissenschaftliches Arbeiten. W3L GmbH, 2. Auflage, 2011
- H. Hering, L. Hering: Technische Berichte. Springer Vieweg, 7. Auflage, 2015

**Special notes**

- The completion period from the topic being set to the submission of the Bachelor’s thesis may not exceed three months.
- Exception: If the Bachelor’s thesis is assigned no later than one month after the start of the 7th semester, the period must not exceed five months.
- With the agreement of the examination committee, the Bachelor’s thesis may be completed in an institution outside the university if supervision by a university’s examiner is guaranteed.