Module Handbook

For the study program

Bionics M.Sc.

Kleve, March 2020 Rev. 1

Content

Curriculum Bionics M.Sc.

Curriculum MB		HPW	Type						Examination form		CP	HPW		
			V	SL	S	Ü	Pra	Pro	Attestation	graded		SS 1	WS	SS 3
Core modules														
Module Code	**Module**													
3300	Research Methods for Engineers	3	1			1	1		x		5		x	
3301	Numerical Methods of Simulation	3	2			1				x	5		x	
3302	General Management	3	2				1		x		5	x		
3600	Principles of Bionics	3	2				1			x	5	x		
3601	Bionics of Sensing	3	2				1			x	5		x	
Focusfield Robotic*														
Module Code	**Core Moduls**													
3402	Principles of Software Development	3	2				1			x	5	x		
Module Code	**Focusfield Moduls**													
3603	Human Machine Interaction	3	2				1		x		5	x		
3606	Physics of Agent Behaviour	3	2				1			x	5	x		
3407	Computational Multibody Dynamics	3	1				2			x	5	x		
3602	Bioinspired Machine Learning	3	2			1				x	5		x	
3604	Autonomous Robotics	3	2				1			x	5		x	
3605	Evolutionary Algorithms	3	2				1			x	5		x	
Focusfield Materials*														
Module Code	**Core Moduls**													
3608	Sustainability	3	2			1				x	5		x	
Module Code	**Focusfield Moduls**													
3609	Advanced Chemistry of Materials	3	2				1			x	5	x		
3611	Bioplastics	3	2				1		x		5	x		
3613	Biomimetic Engineering Materials	3	2				1			x	5	x		
3403	Materials Selection and Simulation	3	2				1			x	5	x		
3610	Smart Materials and Surface Technology	3	2				1			x	5		x	
3612	Leightweight Materials and Joining	3	2				1			x	5		x	
Final Semester														
Module Code	**Module**													
3303	Applied Research Project (ARP)										5			x
3304	Master thesis										22			x
3305	Colloquium										3			x

Explanations

* Die Fakultät behält sich das Recht vor, sowohl eine Mindestteilnehmerzahl für das Zustandekommen eines Fokusfeldes / Wahlbereiches als auch eine Maximalteilnehmerzahl festzulegen. / * The faculty reserves the right to determine a minimum and a maximum number of participants for offering a focus fields / electives.

Abbreviations

HPW	Semesterwochenstunden / hours per week
CP	Kreditpunkte / credit points

Core Modules

3300 Research Methods for Engineers

Module name:	Research Methods for Engineers
Module code:	3300
Semester:	Winterterm
Module coordinator:	Prof. Dr. Andy Stamm
Lecturer:	Prof. Dr. Andy Stamm
Language:	English
Place in curriculum:	Common Core subject
Timetabled hours:	Lectures: 1 HPW Tutorials: 1 HPW Laboratory Sessions: 1 HPW
Workload:	45 h attendance 75 h preparation and review 30 h report preparation
Credits:	5
Recommended prerequisites:	Basic courses in programming, electronics, engineering design, CAD, and materials.
Module objectives:	After completing the course the students have experience of project related work and the practical implementation of their acquired knowledge. They can find relevant information independently using a variety of sources. They can construct useful theories, hypotheses and work statements, then document and present their work in a professional manner. They have also learned the practical side of engineering science with introductions to instrumentation and measurement in real environments. They have learned to design and make their own test rigs and to interpret the data obtained with instrumentation they built and debugged themselves.
Content:	• Introduction to Engineering Research • Literature Search & Review • Developing a Research Plan • Statistical Design and Analysis • Optimisation Techniques • Design and Construction of Experimental Apparatus • Instrumentation • Amplifier Design and Data Acquisition • Software Control of Experimental Aparatus

	• Signal in Noise Considerations • Filter Design: Mechanical, Electrical and Software • Numerical Treatment of Experimental Data • Qualitative Research Methods • Report Writing and Presentation • Collaborative Working & Resource Planning; Gantt Charts; Online Collaboration Tools
Assessment:	Attestation: Written reports and oral presentations
Forms of media:	Whiteboard, PowerPoint, Projector, Online
Literature:	Lecture notes - Thiel DV (2014) Research methods for engineers. Cambridge UP. ISBN 978-1-139-54232-6 - Horowitz & Hill. The art of electronics. Cambridge UP. ISBN 978-0-521-80926-9

3301 Numerical Methods of Simulation

Module name:	Numerical Methods for Simulation
Module code:	3301
Semester:	Winterterm
Module coordinator:	Prof. Dr. Alexander Struck
Lecturer:	Prof. Dr. Alexander Struck
Language:	English
Place in curriculum:	Common Core module
Timetabled hours:	Lectures: 2 HPW Exercises: 1 HPW
Workload:	45 h attendance 75 h preparation and review 30 h exam preparation
Credits:	5
Recommended prerequisites:	
Module objectives:	• Learning some standard concepts of mathematical modelling and computer simulation • Getting an overview of numerical methods for solving algebraic, differential and differential-algebraic equations • Developing computer models for small problems and investigating benefits and limitations of the models and their simulation
Content:	• Presentation of numbers in a computer: integers and floating point variables; roundoff errors • Loss of significant digits, error propagation • Interpolation: Lagrange polynomials and splines • Differentials and differential equations by finite differences, transformation to iterative algebraic equations • Iterative solution of linear systems • Iterative solution of non-linear systems, Newton's Method, Newton-Raphson • Integration schemes for ordinary and partial differential equations: forward and backward Euler, velocity Verlet, Runge-Kutta, implicit vs. explicit schemes • Stability, accuracy and consistency of integration schemes • Fixed-point iteration • Numerical solution of differential equations: forward and backward Euler, Runge-Kutta, difference equations, stability

	• Numerical Solution in real-time systems • Numerical Computation of Eigenvalues
Assessment:	Graded: Examination
Forms of media:	Whiteboard, Beamer, Computer for numerical exercises
Literature:	1. Forman S. Acton (2005) *Real Computing Made Real – Preventing Errors in Scientific and Engineering Calculations*. Mineola. Dover Publications. 2. Richard Burden and Douglas Faires (2011) *Numerical Analysis*. 9th international edition. Brooks/Cole. 3. Parviz Moin (2010) *Fundamentals of Engineering Numerical Analysis*. 2nd edition. Cambridge. Cambridge University Press. 4. Cleve Moler, *Numerical Computation with Matlab*, free pdf from https://de.mmathworks.com/moler/chapters.html 5. Teukolsky, Press: Numerical Recipes, Princeton University Press

3302 General Management

Module name:	General Management
Module code:	3302
Semester:	Summerterm
Module coordinator:	Prof. Dr.-Ing. Dirk Untiedt
Lecturer:	Prof. Dr.-Ing. Dirk Untiedt
Language:	English
Place in curriculum:	Core subject
Timetabled hours:	Lectures: 2 HPW Practical Training: 1 HPW
Workload:	45 h attendance 65 h preparation and review 40 h report preparation
Credits:	5
Recommended prerequisites:	None
Module objectives:	In addition to the corporate management mostly three management functions for any kind of company can be distinguished with respect to general Management: • Marketing Management • Finance Management and • Production management Students know the main tools, methods and instruments of general management. They have the ability to use them effectively. They are able to formulate strategies and implementation plans on all strategy levels and in specific contexts.
Content:	• Fundamentals of General Management • Strategy Formulation • Operations • Finance and Controlling • Human Resource Management • Change Management • Marketing and Sales
Assessment:	Attestation: Written reports and oral presentations
Forms of media:	Whiteboard, PowerPoint, Business Simulation Software
Literature:	• Lecture notes • David Hunger; Thomas L. Wheelen: Essentials of Strategic Management. Pearson Education, Inc.

	Publishing as Prentice Hall, 5th international edition 2010.

3600 Principles of Bionics

Module name:	Principles of Bionics
Module code:	3600
Semester:	Summerterm
Module coordinator:	Prof. Dr. William Megill
Lecturer:	Prof. Dr. William Megill
Language:	English
Place in curriculum:	Common Core Subject
Timetabled hours:	Lectures: 2 HPW Practical Training: 1 HPW
Workload:	45 h attendance 75 h Lab reports and review 30 h exam preparation
Credits:	5
Prerequisites:	
Module objectives:	Students know the underlying principles of the developing field of bionics / biomimetics, including recent VDI guidelines that shape the field in Germany. They can tell the difference between biomimetic engineering design and marketing storytelling. They know the steps in a technical development process. They understand the importance of communication and interdisciplinary collaboration in the success of design projects. They are able to make use of tools to identify a customer's requirements, and of other tools to develop new ideas and potentials. At the end of the course, the students should be able to apply biomimetic design rules to development projects. Students have internalised an inventory of biological case studies (archetypes) which are the basis for modern biomimetic design. They will have acquired knowledge and techniques to understand and classify movement processes in biology so that these can be transferred to a technical context.
Content:	Brief history of bionics/biomimetics What's in a word - bionics/biomimetics/bioinspiration - finding a title for an interdisciplinary field. Mythbusters, bionics and philosophy: What is biomimetic, and what isn't; Convergent evolution in biology and technology; bionics as a marketing tool; Nature isn't always best; contrasts in philosophies & approaches of

	engineering and biology; communication in interdisciplinarity. Biomimetic Product Design: Review of engineering design; bionics and the German norm: VDI 2220; Creativity tools including TRIZ/BioTRIZ, ontologies; Case Studies in Bionics of Locomotion: Biomimetic principles will be developed starting from animal examples and leading to novel machine implementations. Locomotion in fluids; drag, propulsion and lift; efficient & tuned body design; fluid-structure interaction; scaling principles; great flight diagram; terrestrial locomotion; importance of resonance and timing; Alongside the technical applications and animal examples, the underlying physics will be taught, specifically mechanics, fluid dynamics and energy use. Traditional wheel-based robots will be contrasted against biological models.
Assessment:	Written examination and Laboratory reports
Forms of media:	Whiteboard, PowerPoint, Projector, Laboratories
Literature:	Course materials from the lecturer Exercises from the lecturer Journals: • Bioinspiration & Biomimetics • Journal of Bionic Engineering • Journal of experimental Biology Further Reading: • BK Ahlborn – Zoological Physics. Springer. • Y. Bar-Cohen Biomimetics Biologically Inspired Technologies. CRC Press, 2006, ISBN: 978-0-8493-3163-3

3601 Bionics of Sensing and Materials

Module name:	Bionics of Sensing and Materials
Module code:	3601
Semester:	Winterterm
Module coordinator:	Prof. Dr. Lily Chambers
Lecturer:	Prof. Dr. Lily Chambers
Language:	English
Place in curriculum:	Common Core Subject
Timetabled hours:	Lectures: 2 HPW Practical Training: 1 HPW
Workload:	45 h attendance 75 h Lab reports and review 30 h exam preparation
Credits:	5
Recommended prerequisites:	Biology/ Chemistry/ Materials Chemistry.
Module objectives:	Biological materials and sensors provide solutions to advance robotics and their interactions with their environment. The module objectives will be to understand natural sensory systems and their transduction pathways along with the material science and engineering of bio-inspired and bio-compatible applications for robotics. Critically appraise research advances in bio-inspired robotics and sensing systems including vision, haptics and flow sensing. Develop an advanced knowledge of soft and smart materials for bionics.
Content:	• Detailed biology of natural sensing systems; vision, hearing, touch (including distant touch), smell, taste, electrogenic, magnetic with a focus on their neural transduction pathways. • Review state-of-the-art biomimetic sensing systems including flow sensors, haptics, optics. • Introduction to biological materials and the key physical phenomena governing them for both plants and animals, including proteins, polysaccharides, ceramics and fibrous composites. • Introduction to biological materials and systems for the design of soft and smart robotic structures and actuation. • In a series of laboratories, practical training will be received to build and test bionic mimics of three

	key sensing systems in the field of Vision, Audition and Flow sensing
Assessment:	Graded: Written examination and Laboratory reports
Forms of media:	Whiteboard, PowerPoint, Projector, Laboratories
Literature:	• F. G. Barth, J. A. C. Humphrey, T. W. Secomb (Eds.): Sensors and Sensing in Biology and Engineering. Springer Berlin, 2003. ISBN: 978-3-211-83771-9 • Y. Bar-Cohen: Biomimetics Biologically Inspired Technologies. CRC Press, 2006, ISBN: 978-0-8493-3163-3 • JFV Vincent (2012) Structural Biomaterials, 3rd Ed. Prince- ton UP. Course materials from the lecturer Exercises from the lecturer Further Reading: Journals Soft robotics Journal Bioinspiration and Biomimetics

Focus Field Robotic

3402 Principles of Software Development

Module name:	Principles of Software Development
Module code:	3402
Courses (where applicable):	
Semester:	Summerterm
Module coordinator:	Prof. Dr. Ronny Hartanto
Lecturer:	Prof. Dr. Ronny Hartanto
Language:	English
Place in curriculum:	Focus Core subject
Timetabled hours:	Principles of Software Development Lectures: 2 HPW Practical: 1 HPW
Workload:	45 h attendance 45 h preparation and review 30 h homework and lab review 30 h exam preparation
Credits:	5
Recommended prerequisites:	Good knowledge in programming (C++, Java, C, etc.) Basic knowledge in object-oriented programming (OOP)
Module objectives:	• Students are familiar with different software process models. • Students are able to classify different aspects of software-related process activities and can recognize the importance of the roles of the parties involved into these processes. • Students are able to derive the software specifications from the requirements of a software project. • Students are familiar with different UML diagrams • Students can develop system model of a software project using graphical modelling (UML) • Students can develop test procedures for software projects. • Students can develop software using reusable software development technique, e.g. using open source libraries • Students can apply some of design pattern techniques • Students can use software repository system for daily purpose, e.g. revision system for a software project
Content:	• Software processes

	- Software process models (Waterfall model, incremental model, reuse-oriented software design) - Process activities (Specification, Design and implementation, Verification, Software evolution) - Coping with change • Agile Development • Requirements Engineering - Functional and non-functional requirements - Requirements specification - Requirements management • Design and Implementation • Design Patterns • Reusable Software Development Technique • System Modelling - Graphical Modelling perspectives (external, interaction, structural and behavioural) - Unified Modelling Language / UML diagrams (activity, use case, sequence, class and state) • Software testing • Software development tools
Assessment:	Graded: Continuous assessment (10%: project and quizzes) and written examination (90%)
Forms of media:	Whiteboard, PowerPoint, Projector, PC-Pool
Literature:	I. Somerville, “Software Engineering”. 10th edition. Pearson 2016 J. Rumbaugh, I. Jacobson, G. Booch, “The Unified Modeling Language Reference Manual”, 2nd edition. Addison-Wesley 2005 S. McConnell, “Code Complete”. 2nd edition. Microsoft Press Redmond, WA, USA 2004. E. Gamma, R. Helm, R. Johnson, J. Vlissides, “Design Patterns: Elements of Reusable Object-Oriented Software”. Addison-Wesley 1995 B. Stroustrup, “The C++ Programming Language”. 4th edition. Addison-Wesley 2013. H. Partsch, “Requirements Engineering systematisch”. Springer 2010 J. A. Whittaker, “How to break software: a practical guide to testing”. Addison-Wesley 2002

3603 Human Machine Interaction

Module name:	Human Machine Interaction
Module code:	3603
Semester:	Summerterm
Module coordinator:	Prof. Dr.-Ing. Ivan Volosyak
Lecturer:	Prof. Dr.-Ing. Ivan Volosyak Prof. Dr. Matthias Krauledat
Language:	English
Place in curriculum:	Focus field
Timetabled hours:	Lecture: 2 HPW Practical Training: 1 HPW
Workload:	45 h attendance 65 h preparation and review 40 h exam preparation
Credits:	5
Prerequisites:	
Module objectives:	The field of Human-Computer Interaction (HCI) is rapidly growing area of human-machine interaction. This highly multidisciplinary study course brings together research topics from: Interaction Design, Human-Robot Interaction, Artificial Intelligence, Psychology, Robotics and many other fields. The main goal of HCI is to enable machines to successfully interact with humans. The students understand the fundamentals of underlying technologies, as they relate to human-computer interaction, man-machine coupling, and ethics. The electrical potentials in the human brain, which can be detected with non-invasive and invasive methods, may be used for the establishing the connection between the human brain and the computer. The students can derive, from first principles, real architectures for modern Brain-Computer Interfaces (BCI). They are able to design and build, using specialized communications structures and sensors, systems for, among other things, the support of physically handicapped individuals (such as gesture recognition, speech processing etc.). They appreciate the safety and social aspects of modern HCI and BCI technologies and can name the relevant risks
Content:	• Introduction to Human-Machine Interaction • Human body as electrical system • The concept of a Brain-Computer Interface • Modern speech processing

	• Gesture recognition • Virtual and Augmented Reality • Data collection with non-invasive methods • Fundamentals of EEG • SSVEP, P300 and ERD/ERS based BCI • Applications for communication with and control of external machines
Assessment:	Attestation
Forms of media:	Whiteboard, PowerPoint, Projector, Demonstrations in the lecture
Literature:	• Ian McLoughlin, Applied Speech And Audio Processing: With Matlab Examples, Cambridge University Press, 2009, 00/YGK 2 • J. R. Parker, Algorithms for image processing and computer vision, 2011, Wiley, 00/TVV 51 • Jonathan R. Wolpaw, Elizabeth W. Wolpaw Brain-Computer Interfaces – Principles and Practice, Oxford University Press, 2012, 00/TVU33 *Further reading:* • Siuly Siuly, Yan Li, Yanchung Zhang EEG Signal Analysis and Classification, Springer, 2016, 00/WBK105 • Rajesh P. N. Rao Brain-Computer Interfacing, Cambridge University Press, 2013, 00/WBK78 • Course materials from the lecturer

3606 Physics of Agent Behaviour

Module name	Physics of Agent Behaviour
Module code	3606
Semester	Summerterm
Module coordinator	Prof. Dr. William Megill
Lecturers	Prof. Dr. William Megill Prof. Dr. Alexander Struck
Language	English
Timetabled hours	Lectures: 2 SWS Practical Training: 1 SWS
Workload	45 h Attendance 65 h Self-study 40 h Exam preparation
Credits	5
Recommended prerequisites:	
Module objectives	• Students are familiar with fundamentals of kinematics, kinetics, agents and mobile robots. • Students are familiar with different locomotion concepts for ground-based robots (wheeled and un-wheeled), aerial robots and naval systems. • Students are able to derive the kinematic model of a mobile agent and understand the physics of agent interaction. • Students understand the fundamentals of ethology, agent behaviour and social robotics. They understand how these fields are studied, what the central tenets are, and what the limitations are. They appreciate the challenges of applying biomimetic solutions to real technical problems. • Students appreciate the complexity of multi-agent interactions and the development of social behaviour in animals, humans and robots. They understand self-organisation as an extension of self-assembly, and appreciate its opportunities, challenges and limits.
Content	Equations of motion for robotics - kinematics of wheeled, legged, swimming and flying agents (robots or animals); Terrestrial locomotion; importance of resonance and timing; wheels, slip and steering. Locomotion in fluids: drag, propulsion and lift; efficient & tuned body design; fluid-structure interaction; scaling principles; great flight diagramme;

	Introduction to the concept of an "agent" in robotics context. Principles of ethology as relevant to bioinspired robotics. Multi-agent interaction in robots and systems; self-assembly; rules and algorithms. Animal & robotic social systems; collaborative working; simple agent complex behaviour. Systems of agents: top-down, bottom-up or wasp waist systems control. Thermodynamics & gas laws in agent (animal or robot) behaviour.
Assessment	Graded: Written examination, lab reports
Forms of media	Whiteboard, PowerPoint, projector, laboratories
Literature	• BK Ahlborn – Zoological Physics. Springer. • Y. Bar-Cohen Biomimetics Biologically Inspired Technologies. CRC Press, 2006, ISBN: 978-0-8493-3163-3 • J.-Ch. Zufferey Bio-inspired Flying Robots. CRC Press, 2008. ISBN: 978-2-940222-19-3 • Siegwart R, Nourbakhsh IR, Scaramuzza D. Introduction to autonomous mobile robotics. MIT Press, 2011. ISBN: 978-0-262-01535-6

3407 Computational Multibody Dynamics

Module name:	Computational Multibody Dynamics
Module code:	3407
Semester:	Summerterm
Module coordinator:	Prof. Dr. Thorsten Brandt
Lecturer:	Prof. Dr. Thorsten Brandt
Language:	English
Place in curriculum:	Focus field
Timetabled hours:	Lectures: 1 HPW Practical Training: 2 HPW
Workload:	45 h attendance 75 h preparation and review 30 h exam preparation
Credits:	5
Recommended prerequisites:	Fundamentals of Mechanics and Engineering Mathematics at the undergraduate level as wells as fundamental programming skills
Module objectives:	After successfully finishing the module, students are familiar with the fundamentals of multibody dynamics. They are able to apply concepts from linear algebra such as vectors and matrices to mechanical systems. The kinematics of technical joints such as revolute joints can be modeled by algebraic constraints by the student. The student is also able to model the dynamics of constraint multibody dynamic systems. Furthermore, the student is able to develop basic programming code and to simulate multibody dynamic systems and to interpret the simulation results.
Content:	The course focuses on the modelling and numerical simulation of dynamic multibody systems. Main subjects are: • Definitions: bodies, joints, and coordinates • Kinematics: rotation, translation • Kinematic constraints • Dynamics • Development of multibody dynamics simulation code • Application of multibody simulation software • Analysis of multibody dynamic systems
Assessment:	Graded: Written or oral examination
Forms of media:	Whiteboard, PowerPoint, Projector
Literature:	P. E. Nikravesh: Planar Multibody Dynamics - Formulation, Programming, and Application, CRC press,2008 Lecture Notes

3602 Bioinspired Machine Learning

Module name:	Bioinspired Machine Learning
Module code:	3602
Semester:	Winterterm
Module coordinator:	Prof. Dr. Matthias Krauledat
Lecturer:	Prof. Dr. Matthias Krauledat
Language:	English
Place in curriculum:	Focus Field Subject
Timetabled hours:	Lectures: 2 HPW Exercises: 1 HPW
Workload:	45 h attendance 75 h preparation and review 30 h exam preparation
Credits:	5
Prerequisites:	Linear Algebra (Eigenvectors, Eigenvalues, Symmetric Matrices, Positive Definiteness, Matrix factorizations, Orthogonality, SVD, Projections, Linear Transformations) Probability Theory (random variables, Expected Value, Variance, Probability Distributions such as Normal Distribution, Statistical testing, Significance levels)
Module objectives:	After completion of the course the students have a general overview of the Machine Learning field. They know details about implementations of various classification and regression methods and understand the mathematical background of the corresponding algorithms. Students are able to select suitable methods to given problems, apply algorithms (based on the respective application fields) and evaluate their performance according to different cost functions.
Content:	Introduction to Machine Learning Classification, Regression, Supervised Learning, Unsupervised Learning, Reinforcement learning Bayesian Decision Theory

	Losses, Risks, Discriminant Functions Multivariate Methods Multivariate Normal Distribution, Classification, Regression Dimensionality Reduction PCA, Multidimensional Scaling, LDA Clustering Mixture Densities, k-means, EM algorithm, Hierarchical Clustering Multilayer Perceptrons / Neural Networks Perceptrons, Training, Backpropagation, Recurrent Neural Networks, Deep Learning Kernel Machines Optimal Hyperplanes, Soft Margin, SVM, Kernel trick Combining Multiple Learners Voting, Bagging, Boosting, Mixture of Experts Design and Analysis of Machine Learning Experiments Cross Validation, Resampling Methods, Guidelines for ML experiments, Measuring Classifier Performance, Comparing two or more Classification algorithms Applications: Object Recognition, Image Classification and others
Assessment:	Graded: Written examination
Forms of media:	Whiteboard, PowerPoint, Projector, Programming lab exercises
Literature:	Alpaydin: Introduction to Machine Learning, 2nd edition, ISBN 978-0262012430, The MIT Press, 2010 Duda, Hart, Stork: Pattern Classification, 2nd edition, ISBN 978-0471056690, Wiley, 2001 Bishop: Pattern Recognition and Machine Learning, ISBN 978-0387310732, Springer, 2006

	Schölkopf, Smola: Learning with Kernels, ISBN 978-0262194754, The MIT Press, 2002 Course materials from the lecturer Exercises from the lecturer Further Reading: Ertel: Introduction to Artificial Intelligence, ISBN 978-0857292988, Springer, 2011 Russell, Norvig: Artificial Intelligence – a modern approach, 3rd edition, ISBN 978-0132071482, Pearson, 2010

3604 Autonomous Robotics

Module name:	Autonomous Robotics
Module code:	3604
Semester:	Winterterm
Module coordinator:	Prof. Dr. Ronny Hartanto
Lecturer:	Prof. Dr. Ronny Hartanto
Language:	English
Place in curriculum:	Focus Field Subject
Timetabled hours:	Lectures: 2 HPW Practical Training: 1 HPW
Workload:	45 h attendance 45 h preparation and review 30 h homework and lab review 30 h exam preparation
Credits:	5
Recommended prerequisites:	Linear Algebra (Symmetric Matrices, Matrix factorizations, Orthogonality, SVD, Projections, Linear Transformations) Probability Theory (random variables, Expected Value, Variance, Probability Distributions such as Normal Distribution, Statistical testing, Significance levels) Mechanics background at undergraduate level Control background at undergraduate level Programming knowledge (C++, C, python)
Module objectives:	Students are familiar with different concepts of mobile robots. Students are familiar with different locomotion concepts for ground-based robots (wheeled and un-wheeled), aerial robots and naval systems. Students are able to derive the kinematic model of a mobile robot. Students are familiar with various sensors and actuators used in the mobile robotics. Students know the principle of self-localization and mapping. Students are familiar with various algorithms used in mobile robotics.

	Students are familiar with communication middleware techniques, such as RPC, Publish/Subscribe Students are familiar with robotics middleware especially in ROS (Robot Operating System) Students can run and write simple program using ROS package for controlling a mobile robot
Content:	Concept of mobile robots, Locomotion, Kinematics, Sensors, Perception, Actuators, Localization, Mapping, Control architectures, Planning and navigation, Communication Middleware, Robotics Middleware.
Assessment:	Graded: Continuous assessment (10%: homework and quizzes) and written or oral examination (90%)
Forms of media:	Whiteboard, PowerPoint, Projector
Literature:	R. Siegwart, I.R. Nourbakhsh, D. Scaramuzza: “Introduction to Autonomous Mobile Robots”, second edition, MIT Press, 2011. B. Siciliano, L. Sciavicco, L. Villani, G. Oriolo: “Robotics: Modelling, Planning and Control”. Springer, 2009. A.S. Tanenbaum, M. van Stehen: „Distributed Systems: Principles and Paradigms“. Prentice Hall, 2002. W. Newman: “A Systematic Approach to Learning Robot Programming with ROS”, 1st edition. Chapman and Hall, 2017.

3605 Evolutionary Algorithms

Module name:	Evolutionary Algorithms
Module code:	3605
Semester:	Winterterm
Module coordinator:	Prof. Dr. Achim Kehrein
Lecturer:	Prof. Dr. Achim Kehrein
Language:	English
Place in curriculum:	Focus Field Subject
Timetabled hours:	Lectures: 2 HPW Practical Training: 1 HPW
Workload:	45 h attendance 45 h preparation and review 30 h homework and lab review 30 h exam preparation
Credits:	5
Prerequisites:	Programming knowledge (C++, C, Python, or MATLAB) Calculus: optimization problems of one and several variables Descriptive statistics: mean, variance, standard deviation, histograms Probability theory: random variables; expected value; variance; discrete and continuous probability distributions, in particular normal distribution
Module objectives:	Students learn the basic principles of biological evolution and how to interpret and apply them as heuristics for general problem solving. Students practice studying scientific literature.

	Students code evolutionary algorithms, run and evaluate computer simulations to solve problems.
Content:	Distinction between optimization problems and constraint satisfaction problems Building blocks of evolutionary algorithms: representation of solution candidates, selection of parents, reproduction: recombination and mutation, selection for next generation Phenotypic and genotypic representation of individuals Binary representation: simple conversion and Gray coding; bit-flip mutation; n-point crossover Population dynamics: effect of parameter settings Importance of randomness for evolutionary algorithms; technical aspects of pseudo-random number generation and statistical evaluation of simulation results Case studies
Assessment:	Graded: Written examination
Forms of media:	Whiteboard, PowerPoint, Projector, demonstration in the lecture
Literature:	K.A. de Jong *Evolutionary Computation – A Unified Approach*. MIT Press, 2006. ISBN: 978-0-262-04194-2 Z. Michalewicz, D.B. Fogel *How to Solve It: Modern Heuristics.* 2nd edition. Springer. 2004. ISBN: 978-3-540-22494-5 M. Mitchell *An Introduction to Genetic Algorithms* (Complex Adaptive Systems). MIT Press, 1998. ISBN: 978-0-262-63185-3 D. Dasgupta, Z. Michalewicz (eds.) *Evolutionary Algorithms in Engineering Applications*. Springer, 1995. ISBN: 978-3-540-62021-1 R.L. Haupt, D.H. Werner *Genetic Algorithms in Electromagnetics*. Wiley, 2007. ISBN: 978-0-471-48889-7 R.L. Haupt, S.E. Haupt *Practical Genetic Algorithms*. Wiley, 2004. ISBN: 978-0-471-45565-3 S. Nolfi, D. Floreano *Evolutionary Robotics: The Biology, Intelligence and Technology of Self-Organizing Machines*. MIT Press, 2004. ISBN: 978-0-262-64056-5

	S.C. Stearns, R.F. Hoekstra *Evolution*. 2nd edition. Oxford University Press. 2005. ISBN: 978-0-199-25563-4

Focus Field Materials

3608 Sustainability

Module name:	Sustainability
Module code:	3608
Semester:	Winterterm
Module coordinator:	Prof. Dr.-Ing. Raimund Sicking
Lecturer:	Prof. Dr.-Ing. Raimund Sicking
Language:	English
Place in curriculum:	Core Subject
Timetabled hours:	Lecture: 2 SWS Exercises: 1 SWS
Workload:	45 h attendance 30 h preparation of presentation(s) 75 h self study and exam preparation
Credits:	5
Recommended prerequisites:	none
Module objectives:	After completing the course, students • understand the general interdependencies between human beings, technology and nature. • can distinguish between different dimensions of globalization. • are aware of global environmental changes, such as climate change. • have fundamental knowledge about sustainability concepts, strategies and areas of activity. • understand concept and principle of a circular economy. • know EU-directives and selected national regulations concerning circular economy and waste • know options for product and product integrated environment protection • recognize concept and structure of different life cycle assessments. • are able to apply methods for sustainable technology design. • Know methods for pollution-free environment
Content:	• Theories of nature, society and technology • Economic, political, cultural and ecological dimension of globalization

	• Global warming, carbon footprint, decarbonization
	• Weak and strong sustainability
	• The *factor 10* approach
	• Concept of
	  - dematerialization
	  - open lool
	  - low carbon
	  - restoration
	• Concept and principle of a circular economy
	• Basics of product and product-integrated environmental protection
	• Technology assessment
	• Social, ecological and classic life cycle assessment (LCA)
	• Low impact materials, renewable resources, energy efficiency, design for reuse and recycling
	• Handling harmfull substances
	• Methods for pollution-free environment

Assessment:	Graded: Examination + Group Presentation
Forms of media:	Whiteboard, Power Point, Projector
Literature:	*Matthias Bank:* Basiswissen Umwelttechnik: Wasser, Luft, Abfall, Lärm und Umweltrecht *Karl Schwister:* Taschenbuch der Umwelttechnik *Ernst Worell, Markus A. Reuter (Ed.):* Handbook of Recycling *Iris Pufé* Nachhaltigkeit - Course materials from the lecturer - Exercises from the lecturer - Lecture notes compiled by class (open source)

3609 Advanced Chemistry of Materials

Module name:	Advanced Chemistry of Materials
Module code:	3609
Semester:	Summerterm
Module coordinator:	Prof. Dr. Neil Shirtcliffe
Lecturer:	Prof. Dr. Neil Shirtcliffe
Language:	English
Place in curriculum:	Focus Field Subject
Timetabled hours:	Lectures: 2 SWS Practical Training: 1 SWS
Workload:	45 h attendance 75 h self study 30 h exam preparation
Credits:	5
Recommended prerequisites:	Fundamentals of Chemistry
Module objectives:	After completing the course, students will be able to describe mechanisms of chemical reactions between organic compounds. Be able to identify stereoisomers have a sound understanding of Redox chemistry, electrochemistry, photochemistry and radical chemistry. be able to characterize chemical reactions by thermodynamic assessment. understand a phase diagram, e.g Pourbaix be able to describe different aspects in nanostructured materials fabrication and characterization
Content:	Chemical structure and functionality of biomaterials, artificial polymers and gels Reaction mechanisms Principles of polymerization Standard reactions in biomaterials Redox-potential, Nernst-equation, electro-kinetic potential (Zeta potential), Redox reactions in biological systems, electrochemistry

	Reaction enthalpy and entropy, Gibbs free enthalpy, Equilibrium constant, reaction order, rate constant, catalysis Macromolecular and Supramolecular chemistry Phase boundaries, solubility Nanochemistry and structured materials characterization and aspects of nanotechnology.
Assessment:	Graded: Written examination
Forms of media:	Whiteboard, Power Point, projector, chemical lab equipment
Literature:	Lecture notes Solomons, Fryhle, Snyder: Organic Chemistry, 12th edition, Wiley 2017 Cowie, Arrighi: Polymers: Chemistry and Physics of Modern Materials, 3rd edition, CRC Press 2007 Geoffrey A Ozin, André Arsenault, Ludovico Cademartiri: Nanochemistry: A Chemical Approach to Nanomaterials

3611 Bioplastics

Module name:	Bioplastics
Module code:	3611
Semester:	Summerterm
Module coordinator:	Prof. Dr. Christoph Heß
Lecturer:	Prof. Dr. Christoph Heß
Language:	English
Place in curriculum:	Core subject
Timetabled hours:	Lectures: 2 SWS Practical Training: 1 SWS
Workload:	45 h attendance 75 h self study 30 h exam preparation
Credits:	5
Recommended prerequisites:	Fundamentals of Chemistry, Non-metallic Materials, Processing of synthetic Materials / Polymer Processing
Module objectives:	After completing the course, students • know the chemical structure of the most important biobased and biodegradable polymers and fibers. • understand the general principles of compounding and processing of thermoplastic, thermosetting and composite materials. • are able to select the most appropriate bioplastic material and compounding/processing regime for a given task. • are aware of the difference between biodegradable, oxodegradable and compostable products and are able to apply standard EN 13432 for testing the biodegradability and compostability of materials correctly. • know the difference between the share of biobased carbon and the share of biobased raw material in a bioplastic. They are able to apply ASTM 6866 for the determination of biobased carbon in a material with the help of radiocarbon dating (^{14}C). • have a sound understanding about the differences between terrestrial and marine degradation of materials and are able to professionally contribute to a scientific discussion on microplastic in the sea resp. marine littering.

Content:	• Chemical structure and synthesis of biopolymers (e.g. starch, cellulose, PLA, PHA, PBAT)
	
	• Compounding of bioplastics
	  ○ Principle of twin screw extrusion (machine set-up, processing parameters, screw design, melting, mixing, metering)
	  ○ Extruder periphery (feeder systems, cooling, venting, pelletizing)
	  ○ Biopolymer blends and compounds, purpose of additives, fillers
	  ○ Thermodynamics of compounding
	
	• Processing of bioplastics and applications
	  ○ Injection moulding of (fiber reinforced) thermoplastics and thermosets; shaped articles
	  ○ Blown film extrusion; flexible film
	  ○ Sheet film extrusion, thermoforming
	  ○ Pultrusion, resin infusion and compression moulding of fiber reinforced bioplastics (composites)
	  ○ Thermodynamics of processsing
	
	• Characterization of bioplastics
	  ○ Share of biobased carbon resp. biobased raw material, ASTM 6866, ^{14}C-radiocarbon dating, carbon cycle
	  ○ Drop-in bioplastics (Bio-PE, Bio-PET)
	  ○ End-of-life options for bioplastics, biodegradability, compostability, EN 13432
	  ○ Marine degradation, microplastic

Assessment:	Attestation: Written exam
Forms of media:	Whiteboard, Power Point, Projector, Lab scale polymer processing equipment
Literature:	- Lecture notes - Peacock, Calhoun: Polymer Chemistry, Hanser 2006 - Agassant, Avenas et al: Polymer Processing, Hanser 2017 - Endres, Siebert-Raths: Engineering Biopolymers, Hanser 2011 - Pötsch, Michaeli: Injection Molding – An Introduction, Hanser 2008

3613 Biomimetic Engineering Materials

Module name:	Biomimetic Engineering Materials
Module code:	3613
Semester:	Summerterm
Module coordinator:	Prof. Dr. Amir Fahmi
Lecturer:	Prof. Dr. Amir Fahmi
Language:	English
Place in curriculum:	Focus Field Subject
Timetabled hours:	Lectures: 2 HPW Practical Traning: 1 HPW
Workload:	45 h attendance 75 h preparation and review 30 h exam preparation
Credits:	5
Recommended prerequisites:	Advanced Materials, Nanomaterials and Materials inspired by nature
Module objectives:	The course objectives is to demonstrate the structure-property-process relationship of biomimetic materials engineering prospective based on principles governing the design of biological materials in broad spectrum of applications. A large variety of mimic natural materials with outstanding collective physical, physiochemical, surface and mechanical properties intensively considered. The course is structured in three comprehensive topics: Principle of engineering in biological materials, Design and fabrication basic building blocks mimic biological materials Future developments in biomimetic engineered materials Learning outcome After completing the course the students will be able to: To design properties of active materials based on proved concept from nature

	To understand the structure, properties, and performance at different scales relative to the hierarchical organization of the biomimetic structured materials. To fabricate different types of biomimetic structured materials at different dimensions and length scale To define process and methodologies to design and fabricate biomimetic nanomaterials towards intelligence in morphing structures. To integrate bioinspired functional components within interdisciplinary design work and devices To understand both applications the limitation to mimic the nature in term of design new or improve new functional structured materials
Content:	The course presents comprehensive overview in wide range of functional biomimetic engineered materials and their composition, structure, and properties. It defines methodologies and pathway in the molecular designs of biomineralisation The primary theme in course is bio-inspired structures via self-assembly process and mechanism at different dimensions and length scales. it demonstrates current approaches to engineer biomimetic materials such as self-healing, self-cleaning and molecular imprinting, followed by a detailed evaluation of their structure-property relationships with focus on collective and adaptive properties It describes process and mechanism of nanomaterials formation in mesoscopic arrays toward transformations across extended length macro scales as key challenge in the design of advanced functional components. The course demonstrates characterisation techniques for wide range of bio-inspired structures and properties towards functions.
Assessment:	Graded: Final written examination only
Forms of media:	Whiteboard, PowerPoint, Projector
Literature:	Peter Fratzl, John W.C. Dunlop, Richard Weinkamer “Materials Design Inspired by Nature: Function Through Inner Architecture” Knecht, Marc R.; Walsh, Tiffany R. “Bio-inspired Nanotechnology”

	Wolfgang Pompe, Gerhard Rodel, Hans-Jurgen Weiss, Michael Mertig “Bio-nanomaterials - Designing Materials Inspired By Nature” Tao Deng “Bioinspired Engineering of Thermal Materials” Matteo Santin and Gary Phillips „Biomimetic, Bioresponsive, and Bioactive Materials” Zhenhai Xia “Biomimetic Principles and Design of Advanced Engineering Materials”

3403 Materials Selection and Simulation

Module name:	Materials Selection and Simulation
Module code:	3403
Semester:	Summerterm
Module coordinator:	Prof. Dr.-Ing. Henning Schütte
Lecturer:	Prof. Dr.-Ing. Henning Schütte
Language:	English
Place in curriculum:	Core subject
Timetabled hours:	Lectures: 2 HPW Practical Training: 1 HPW
Workload:	45 h attendance 75 h preparation and review 30 h exam preparation
Credits:	5
Recommended prerequisites:	Introductory courses in Material Science, Design and Mechanics
Module objectives:	After completing the course the students are able to: • classify materials according to specific applications, e.g. according to specific design codes • understand tools and keys for proper selection of materials for specific applications • detect limits of materials and present proper alternative selection • identify standard procedures and benchmarks for materials classification and selection • apply basic materials property calculations • identify and apply proper simulation models and tools, especially FEM based analysis
Content:	• General ideas of materials selection • Methods and procedures • Determination of requirements

	• Information sources and databases • Evaluation, validation and decision • Risk evaluation and control • Overview and application of modelling approaches simulation methods, FEM based evaluation, risk and failure models • Assessment
Assessment:	Graded: 100% continuous assessment
Forms of media:	Whiteboard, PowerPoint, Projector
Literature:	- Lecture notes - Michael Ashby: Materials Selection in Mechanical Design. Butterworth Heinemann; 4th revised edition 2010 - Huei-Huang Lee : Finite Element Simulations with ANSYS Workbench 17 - Guangming Zhang: Engineering Analysis with ANSYS Workbench 18

3610 Smart Materials and Surface Technology

Module name:	Smart Materials and Surface Technology
Module code:	3610
Semester:	Winterterm
Module coordinator:	Prof. Dr. Neil Shirtcliffe
Lecturer:	Prof. Dr. Neil Shirtcliffe
Language:	English
Place in curriculum:	Focus Field Subject
Timetabled hours:	Integrated Seminar and Practical training: 3 SWS
Workload:	45 h attendance 75 h self study 30 h exam preparation
Credits:	5
Recommended prerequisites:	Advanced Chemistry
Module objectives:	After completing the course, students will be able to carried out a small study into one of the areas and have engaged with studies on the others (depending upon student numbers) to understand some simple research topics related to the subject cluster To identify and verify the selection and limitation of smart materials and compartments
Content:	Chemical and biosensing using various methods such as antibody, QCM, electrochemistry, Spectroscopic… Surface treatments using various methods Such as evaporation, plasma, hot wire, layer by layer… Material formation using methods Such as sol-gel, supramolecular chemistry, crystal growth, phase separation Smart systems and hybrid materials for Transducers, Sensors, Piezoelectrics and actuators applications

	Designing smart, structured materials to control responsivity and improve device performance Electroactive and magneto rheological materials Shape memory materials (alloys, polymers,…) Biomimetic smart materials
Assessment:	Graded: Viva voce, written report
Forms of media:	Whiteboard, Power Point, projector, chemical lab equipment
Literature:	Research papers Electrochemical Methods: Fundamentals and Applications by Allen J. Bard (Autor), Larry R. Faulkner (Autor) Supramolecular Chemistry (Oxford Chemistry Primers) by Paul D. Beer Gauenzi, P., Smart Structures, Wiley Gandhi, Thompson, Smart Materials and Structures, Springer Haghi and Zaikov Handbook of Research on Nanomaterials, Nanochemistry & Smart Materials, Nova Science Publishers Inc.

3612 Lightweight Materials and Joining

Module name:	Lightweight Materials and Joining
Module code:	3612
Semester:	Winterterm
Module coordinator:	Prof. Dr.-Ing. Raimund Sicking
Lecturer:	Prof. Dr.-Ing. Raimund Sicking
Language:	English
Place in curriculum:	Focus Field Subject
Timetabled hours:	Lectures: 2 HPW Practical Training: 1 HPW Optional one excursion
Workload:	45 h attendance 45 h preparation and reports 60 h self study and exam preparation
Credits:	5
Recommended prerequisites:	Basic courses in materials science and substance-to-substance joining technologies
Module objectives:	After completing the course the students • will have knowledge to assess light metals, composites, high strength materials and other materials with regard to their suitability for light weight constructions • will understand the principles of traditional engineering joining technologies used for different light and high strength materials
Content:	• Properties of lightweight and high strength materials like aluminium, magnesium, high strength steels, CFRP and others • Material related design aspects for lightweight constructions • Production and manufacturing of an exemplary lightweight material • Welding, soldering and brazing of metals • Glueing and bonding of plastics and composites • Mechanical joining techniques (rivets, bolts, clinching) • Stress concentrations, load transfer across joints, corrosion for selected examples • Combined processing
Assessment:	Graded: Written examination

Forms of media:	Whiteboard, PowerPoint
Literature:	• Lecture notes • Current literature • F. C. Campbell Lightweight Materials • D. Faruk, J. Tjong, M. Sain (Ed.) Lightweight and sustainable materials for automotive applications • K. Srinivasan Composite Materials – Production, Properties, Testing and Applications • C. B. Carter, M. G. Norton Ceramic Materials – Science and Engineering • M. F. Ashby, D. R. H. Jones: Engineering Materials 2 – An Introduction to Microstructures, Processing and Design, 3rd edition, 2006, ISBN-13 978-0-7506-6381-6 • S. Kalpakjian, S. R. Schmid Manufacturing – Engineering and Technology • R. W. Messler Jr. Joining of Materials and Structures • AWS C3 Committee on Brazing and Soldering: Brazing Handbook, 5th edition, 2012, ISBN 978-0-87171-046-8, AWS

Final Semester

3303 Applied Research Project - ARP

Module name:	Applied Research Project - ARP
Module code:	3303
Semester:	Summerterm
Module coordinator:	Prof. Prof. Dr. Dirk Nissing Prof. Dr. Alexander Klein Prof. Dr. William Megill Prof. Dr. Ronny Hartanto
Lecturer:	Project dependent
Language:	English
Place in curriculum:	Core Subject
Timetabled hours:	none
Workload:	150 h
Credits:	5
Recommended prerequisites:	
Module objectives:	The students demonstrate their capability to work independently on an applied research subject in alignment with their course of study, meeting all topical and scientific requirements in a limited period of time. They have the ability to self-analyze and assess the results and make recommendations for improvements. They are able to organize their workflow in order to meet the demands of the problems formulated in their project, as well as to monitor progress and make necessary amendments. Additionally students are able to improve their documentation skills, thus documenting their approach and their results to meet the requirements of a scientific publication.
Content:	The project content depends on the chosen topic and is agreed upon with the supervisor. Documentation is granted by an adequately sized description of the topic/problem, the chosen approach, used methods and results.
Assessment:	Graded: Written documentation, research results, proceeded data and charts, prototypes, software code, blueprints where applicable.
Forms of media:	Raw data, slide deck, written documentation
Literature:	

3304 Master Thesis

Module name:	Master Thesis
Module code:	3304
Semester:	Summerterm
Module coordinator:	Prof. Prof. Dr. Dirk Nissing Prof. Dr. Alexander Klein Prof. Dr. William Megill Prof. Dr. Ronny Hartanto
Lecturer:	Project dependent
Language:	English
Place in curriculum:	Core Subject
Timetabled hours:	none
Workload:	660 h
Credits:	22
Recommended prerequisites:	At least 50 credit points in the respective courses. Successfully passed “Applied Research Project”.
Module objectives:	The students demonstrate their capability to work independently on a scientific subject in alignment with their course of study, meeting all topical and scientific requirements in a limited period of time. Scientific methods and approaches are used in order to work on the subject and they have the ability to analyze and assess the results. They are able to organize their workflow in order to meet the demands of the problems formulated in their theses, as well as to monitor progress and make necessary amendments. Additionally students are able to improve their documentation skills, thus documenting their approach and their results to meet the requirements of a scientific publication.
Content:	The Thesis content depends on the chosen topic and is agreed upon with the supervisor. Documentation is granted by an adequately sized description of the topic/problem, the chosen approach, used methods and results.
Assessment:	Graded: Written thesis
Forms of media:	Written thesis
Literature:	

3305 Colloquium

Module name:	Colloquium
Module code:	3305
Semester:	Summerterm
Module coordinator:	Prof. Prof. Dr. Dirk Nissing Prof. Dr. Alexander Klein Prof. Dr. William Megill Prof. Dr. Ronny Hartanto
Lecturer:	Supervisor of the Master Thesis
Language:	English
Place in curriculum:	Core Subject
Timetabled hours:	none
Workload:	90 h
Credits:	3
Recommended prerequisites:	At least 87 credits
Module objectives:	The students are able to defend the results of the Master Thesis place their work in a context of scientific applications and present their results in a proper form for the audience. They motivate their approach and make estimations, how assumptions and simplifications may affect the validity of their results. Additionally, students are able to analyze questions concerning their thesis and results and answer them properly in the context of professional and extra-professional reference.
Content:	The content is aligned with the content of the Master Thesis, in addition methodological discussions.
Assessment:	Graded: Oral examination
Forms of media:	Whiteboard, PowerPoint, Projector, other relevant media
Literature:	