Technische Hochschule Ingolstadt

Module Handbook

M.Eng. Intelligent Aerial Systems

Faculty of
Electrical Engineering and Information Technology

Study and examination regulation WS 26/27

as of: 2026-06-12

Content

1 Introduction

1.1 Overview

Autonomous flight systems, including drones and future urban air mobility, are considered one of the key technologies of the coming decades, as they offer both environmental and societal benefits. Thanks to AI-supported flight planning and electric propulsion, they operate efficiently and with low emissions. Applications range from the inspection of industrial facilities to the monitoring of ecosystems. Engineers with interdisciplinary knowledge in aerospace, electronics and computer science are particularly wanted. The Master-programme "Intelligent Aerial Systems" (IAS) wants to impart dedicated engineering approaches for the design and implementation of autonomous flight systems.

The programme takes four semesters. Semester 1 prepares students that have been graduated from different engineering disciplines for the subsequent modules. The following two semesters are dedicated to lectures, seminars and projects. The fourth semester is reserved for the Master's thesis. The curriculum of the Master's programme has been tailored towards the intermediation of expertise that is required to work on problems in development of autonomous flight systems. It mediates the special of the engineer-scientific approach. However, scientific oriented work in a master programme means that students learn independently and solely responsible.

Multi-disciplinary modules structure the programme. The subjects of the modules emanate from different engineering areas.

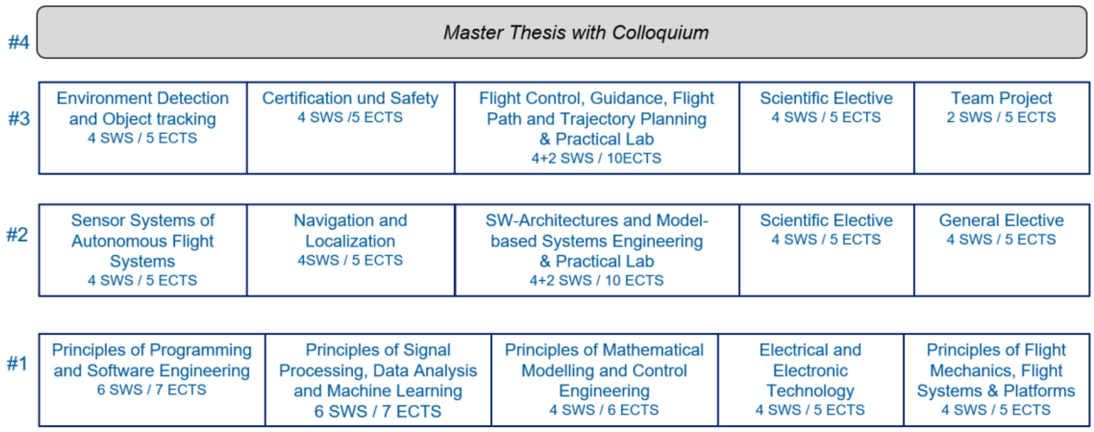

Figure 1: General Programme structure

Compulsory modules aim at transfer of knowledge an engineer of autonomous flight systems must have. The compulsory module Project enables students to incorporate into a new complex task and - based on a division of labor - to work on this task interdisciplinary in a team using suitable scientific methods.

Legal Basis

This module handbook describes the curriculum of the Master's degree program in Intelligent Aerial Systems and its courses in accordance with the General Examination Regulations of the Technical University of Ingolstadt (APO THI) dated July 17, 2023. The curriculum is described in an appendix that applies to all students who have enrolled in M.Eng. Intelligent Aerial Systems at TH Ingolstadt since winter term 2026/27.

In particular, the module handbook specifies the study objectives and content of the individual compulsory modules as well as the division of the semester hours per week per module and semester. It also contains more detailed provisions on course-related performance and attendance assessments. In the event of ambiguities, the higher-level study and examination regulations take precedence.

The list of compulsory and elective courses offered in a specific semester are documented in the study guide for the respective semester. The study guide is published in the Moodle course room dedicated to this degree program.

1.2 Graduation

The Technische Hochschule Ingolstadt awards the academic degree

Master of Engineering (M.Eng.)

1.3 Advisor and Programme Coordinator

For subject-oriented questions and problems, the course advisor is available. Questions related to the organization will be answered by the programme coordinator. Advisor and coordinator is

Prof. Dr. Andreas Hagerer building A, room 107, phone 0841 / 9348-3800

The consultation hours that apply during the semester are announced via Moodle.

2 Basic Structure of the Programme

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

2.1 Compulsories

Start in winter

SPO-No.	Module	Semester 1		Semester 2		Semester 3		Semester 4	
		SWS/ ECTS	Exam	SWS/ ECTS	Exam	SWS/ ECTS	Exam	SWS/ ECTS	Exam
1	Principles of Programming and Software Development	6 / 7	PF						
2	Principles of Signal Processing, Data Analysis and Machine Learning	6 / 7	PF						
3	Principles of Mathematical Modelling and Control Engineering	4 / 6	schrP						
4	Electrical and Electronic Technology	4 / 5	schrP						
5	Principles of Flight Mechanics, Flight Systems and Platforms	4 / 5	schrP						
6	Sensor Systems of Autonomous Flight Systems			4 / 5	schrP				
7	Navigation and Localization			4 / 5	schrP				
8	Software-Architectures and Model-based Systems Engineering			6 /10					
8.1	Software-Architectures and Model-based Systems Engineering			4 / -	schrP				
8.2	Practical Lab SW-Architectures and MBSE			2 / -	LN				
13	General Elective			4 / 5	LN				
14	Scientific Elective			4 / 5	LN				
9	Environment Detection and Object Tracking					4 / 5	schrP		
10	Certification und Safety					4 / 5	mdlP		
11	Flight Control, Guidance, Flight Path and Trajectory Planning					6 / 10			
11.1	Flight Control, Guidance, Flight Path and Trajectory Planning					4 / -	schrP		
11.2	Practical Lab Flight Control and Trajectory Planning					2 / -	LN		
12	Team Project					2 / 5	Proj		
13	Scientific Elective					4 / 5	LN		
18	Master Thesis							0 /30	
18.1	Master Thesis								MA
18.2	Master Thesis Colloquium								Koll
	Sum	24/30		22/30		20/30		0/30	

schrP written exam
Proj project work
SA seminar paper
mdlP oral exam
LN subject-defined exam
PF portfolio exam
MA Master Thesis
Koll Colloquium

Start in summer

SPO-No.	Module	Semester 1		Semester 2		Semester 3		Semester 4	
		SWS/ ECTS	Exam	SWS/ ECTS	Exam	SWS/ ECTS	Exam	SWS/ ECTS	Exam
1	Principles of Programming and Software Development	6 / 7	PF						
2	Principles of Signal Processing, Data Analysis and Machine Learning	6 / 7	PF						
3	Principles of Mathematical Modelling and Control Engineering	4 / 6	schrP						
4	Electrical and Electronic Technology	4 / 5	schrP						
5	Principles of Flight Mechanics, Flight Systems and Platforms	4 / 5	schrP						
9	Environment Detection and Object Tracking			4 / 5	schrP				
10	Certification und Safety			4 / 5	mdlP				
11	Flight Control, Guidance, Flight Path and Trajectory Planning			6 / 10					
11.1	Flight Control, Guidance, Flight Path and Trajectory Planning			4 / -	schrP				
11.2	Practical Lab Flight Control and Trajectory Planning			2 / -	LN				
12	General Elective			4 / 5	LN				
13	Scientific Elective			4 / 5	LN				
6	Sensor Systems of Autonomous Flight Systems					4 / 5	schrP		
7	Navigation and Localization					4 / 5	schrP		
8	Software-Architectures and Model-based Systems Engineering					6 /10			
8.1	Software-Architectures and Model-based Systems Engineering					4 / -	schrP		
8.2	Practical Lab SW-Architectures and MBSE					2 / -	LN		
13	Team Project					2 / 5	LN		
14	Scientific Elective					4 / 5	LN		
18	Master Thesis							0 /30	
18.1	Master Thesis								MA
18.2	Master Thesis Colloquium								Koll
	Sum	24/30		24/30		20/30		0/30	

schrP written exam
Proj project work
SA seminar paper
mdlP oral exam
LN subject-defined exam
PF portfolio exam
MA Master Thesis
Koll Colloquium

2.2 Electives

Scientific Electives

Required scientific elective modules are modules offered to students as part of the degree programme. Each student must complete a total of two elective modules according to the study and examination regulations. The selected modules are handled like compulsory modules. A claim that all scientific elective modules envisaged in a specific semester are offered, does not exist. Likewise, there is no claim that the associated teaching events are carried out if the number of participants is insufficient. Which modules are offered in the respective semester can be found in the study guide of the semester.

General Elective

Basically, students with knowledge of German at level A1/A2 are asked to select modules worth 5 ECTS or modules worth 2.5 ECTS from the catalogue of German language modules offered. If German language modules worth 2.5 ECTS are taken, the number of performance assessments to be completed increases accordingly. A performance assessment must be completed in each module. The performance assessment is graded with the designation “passed” or “failed”. The modules are included in the transcript with the module designation.

Students with knowledge of German at level greater than A2 can select other language modules or modules from non-engineering area.

3 Description of Modules

3.1 Compulsories

Principles of Programming and Software Development			
Module abbreviation	IAE_ProgSW	**Reg.-Nr.**	1
Curriculum	**Study Programme**	**Module type**	**Semester**
	Intelligent Aerial Systems	Einsetzungstext ist leer!	1
Module frequency	winter and summer term	**Module duration**	1 semester

Responsible for module	Hagerer, Andreas		
Lecturer(s)	Hagerer, Andreas		
Language of instruction	English	**Language of exams**	English
Credit points / SWS	7 ECTS / 6 SWS		
Workload	Contact hours Self-study Total		70 h 105 h 175 h
Subjects of the module	Principles of Programming and Software Development		
Lecture types	SU/Ü - lecture with integrated exercises		

Examinations

PF - Portfolio Exam (with exams during the examination period)

Additional explanations regarding examinations

The portfolio exam aims to assess your ability to apply fundamental programming and software development skills in real-world and problem-solving contexts. It consists of three individual examinations

- a practical examination (written test, 30 minutes, (10%, participation required to pass, mid of April))
- a practical examination (programming project) to be submitted online with an interview about code produced (20%, submission and participation required to pass, end of May)
- a computer based written exam (90 minutes, closed book) asking with programming and software development concepts comprehension and writing of short code pieces (70%, examination period)

If an individual examination is not attended, the overall grade will be “not attended” (in German: nicht teilgenommen). The module is passed if about 50% of the marks have been achieved in each part.

Prerequisites according examination regulation

None

Recommended prerequisites

None

Objectives

Upon completion of the module, students will be able to

- know how to use basic data structures and control statements in Python programs.
- design and implement programs to solve real-world problems in Python.
- apply object-oriented concepts.
- know the concepts of the scientific Python ecosystem.

- be familiar with software development concepts like software lifecycle, software specification and UML models.
- apply methods used to plan, develop and engineer software solutions.

Content

- information representation and manipulation by means of variables, data structures, statements and control structures
- structuring programs by means of functions and modules
- introduction to object-oriented programming
- modules and concepts of the scientific Python ecosystem: NumPy, Matplotlib, Scikit-Learn
- phases and characteristics of software processes: requirements engineering, software modeling, design and implementation
- software processes: V-model and MISRA development guideline, process assessment (CMMI, SPICE), model-based development (Matlab/Simulink/Stateflow), supporting processes (e.g. versioning with git, requirements tracing)

Literature

- MATTHES, Eric, 2023. *Python crash course: a hands-on, project-based introduction to programming*. San Francisco: No Starch Press. ISBN 978-1-7185-0270-3
- GUTTAG, John, 2021. *Introduction to computation and programming using Python: with application to computational modeling and understanding data*. Cambridge, Massachusetts ; London, England: The MIT Press. ISBN 978-0-262-54236-4
- PINE, David J., 2019. *Introduction to Python for science and engineering* [online]. Boca Raton ; London ; New York: CRC Press. PDF e-Book. ISBN 978-0-429-01425-3, 978-0-429-50641-3. Available via: https://doi.org/10.1201/9780429506413.
- LANGTANGEN, Hans Petter, 2016. *A primer on scientific programming with Python* [online]. Berlin: Springer. PDF e-Book. ISBN 978-3-662-49887-3. Available via: https://doi.org/10.1007/978-3-662-49887-3.

Additional remarks

None

Principles of Signal Processing, Data Analysis and Machine Learning

Module abbreviation	IAE_SigML	**Reg.-Nr.**	2
Curriculum	**Study Programme**	**Module type**	**Semester**
	Intelligent Aerial Systems	Einsetzungstext ist leer!	1
Module frequency	winter and summer term	**Module duration**	1 semester

Responsible for module	Mecking, Michael		
Lecturer(s)	Mecking, Michael; Neumeier, Marion		
Language of instruction	English	**Language of exams**	English
Credit points / SWS	7 ECTS / 6 SWS		
Workload	Contact hours		70 h
	Self-study		105 h
	Total		175 h
Subjects of the module	Principles of Signal Processing, Data Analysis and Machine Learning		
Lecture types	SU/Ü - lecture with integrated exercises		

Examinations

PF - Portfolio Exam (with exams during the examination period)

Additional explanations regarding examinations

The examination consists of two individual exams:

- a 45-minute written exam before the examination period (33% overall weight, held in week 12 of the semester),
- a 90-minute written exam during the examination period (67% overall weight).

If an individual examination is not attended, the overall grade will be recorded as “not attended” (in German: nicht teilgenommen). The overall exam is considered passed if more than 50% of the weighted points are achieved.

Prerequisites according examination regulation

None

Recommended prerequisites

None

Objectives

Upon completion of the module, students will be able to

- describe and analyse the properties of signals and discrete-time linear systems in the time and frequency domain using discrete-time transforms.
- design linear discrete-time filters with prescribed properties.
- determine the limitations and impact of sampling and quantisation on the conversion of analogue to digital signals.
- apply (fast) Fourier-Transforms to analyse and realise discrete-time signal processing systems.
- understand statistical machine learning (ML).
- identify ML potential and limitations in application domains.
- choose appropriate ML methods, models, and algorithms for a given problem.
- analyze properties of ML models and algorithms.

Content
• fundamentals of discrete-time signals and systems • system analysis and transform techniques • sampling theory • digital filter design and filter implementation • classification tasks and basic learning algorithms • model architectures and learning techniques • models for sequential data • unsupervised learning
Literature
• OPPENHEIM, Alan V. and Ronald W. SCHAFER, 2014. *Discrete-Time Signal Processing*. Harlow: Pearson. ISBN 978-1-29202-572-8 • VAIDYANATHAN, P. P., 2024. *Signals, systems, and signal processing*. Cambridge: Cambridge University Press. ISBN 978-1-00-941229-2 • MURPHY, Kevin P, 2022. *Probabilistic machine learning* [online]. *an introduction*. Cambridge, Massachusetts ; London, England: The MIT Press. PDF e-Book. ISBN 978-0-262-04682-4. Available via: https://probml.github.io/pml-book/book1.html. • VANDERPLAS, Jake, 2023. *Python data science handbook: essential tools for working with data*. Beijing ; Boston ; Farnham ; Sebastopol ; Tokyo: O'Reilly. ISBN 978-1-0981-2122-8
Additional remarks
None

Principles of Mathematical Modelling and Control Engineering

Module abbreviation	IAE_MathCtrlEng	**Reg.-Nr.**	3
Curriculum	**Study Programme**	**Module type**	**Semester**
	Intelligent Aerial Systems	Einsetzungstext ist leer!	1
Module frequency	winter and summer term	**Module duration**	1 semester

Responsible for module	Gregor, Rudolf		
Lecturer(s)	Gregor, Rudolf		
Language of instruction	English	**Language of exams**	English
Credit points / SWS	6 ECTS / 4 SWS		
Workload	Contact hours		47 h
	Self-study		103 h
	Total		150 h
Subjects of the module	Principles of Mathematical Modelling and Control Engineering		
Lecture types	SU/Ü - lecture with integrated exercises		

Examinations

schrP90 - written exam, 90 minutes

Additional explanations regarding examinations

None

Prerequisites according examination regulation

None

Recommended prerequisites

None

Objectives

After successfully completing the module, students are able to

- investigate real technical systems, to structure them into appropriate subsystems and derive suitable differential equations or systems of differential equations.
- analyze control systems and create models in the time and frequency domain.
- analyze systems with regards to dynamics, oscillatory behavior and stability.
- understand the system specifications which a closed-loop circuit must fulfill.
- evaluate and select suitable controller structures in accordance to the specifications.
- apply different methods to parameterize the controller structures and analyze the results in simulations.

Content

- methodological approaches to derive ordinary differential equations from simple electrical and mechanical systems
- different methods to implement linear and non-linear differential equations in Matlab/Simulink (transfer functions, state space representation, ...)
- Laplace-transformation and its fields of application (implementation and analysis of LTI-systems)
- system description and representation in the time and frequency domain
- elementary control loop elements
- control loops: requirements, behavior, design

• controller synthesis: root locus / Bode diagram / empirical approach
Literature
• SUN, Jing, 2018. *Control engineering: fundamentals* [online]. Berlin: De Gruyter. PDF e-Book. ISBN 978-3-11-057327-5. Available via: https://doi.org/10.1515/9783110573275. • BOLTON, William, 2010. *Control engineering*. Harlow u.a.: Prentice Hall. ISBN 978-0-582-32773-3 • DORF, Richard C. and Robert H. BISHOP, 2022. *Modern control systems*. Harlow, England: Pearson. ISBN 978-1-292-42237-4
Additional remarks
None

Electrical and Electronic Technology

Module abbreviation	IAE_ElecTechn	**Reg.-Nr.**	4
Curriculum	**Study Programme**	**Module type**	**Semester**
	Intelligent Aerial Systems	Einsetzungstext ist leer!	1
Module frequency	winter and summer term	**Module duration**	1 semester

Responsible for module	Arnold, Armin		
Lecturer(s)	Arnold, Armin		
Language of instruction	English	**Language of exams**	English
Credit points / SWS	5 ECTS / 4 SWS		
Workload	Contact hours		47 h
	Self-study		78 h
	Total		125 h
Subjects of the module	Electrical and Electronic Technology		
Lecture types	SU/Ü - lecture with integrated exercises		

Examinations

schrP90 - written exam, 90 minutes

Additional explanations regarding examinations

None

Prerequisites according examination regulation

None

Recommended prerequisites

None

Objectives

Upon completion of the module, students will be able to

- have acquainted the special characteristics and specifications of electronic systems.
- understand the specific characteristics of the most important sensors and actuators and are able to select the appropriate components for any given problem.
- know the electric architecture of control units and applied integrated circuits.
- know about different vehicle networks and can explain the communication principles of the corresponding electronic components.

Content

- basics of electrical and electronic engineering
- introduction to sensor and actuator technology
- basic functionalities of different bus systems
- control unit circuits for input and sensor signal conditioning, output drivers and controlling actuators, power supply
- physical layer of communication networks and onboard communication
- introduction to electric standards

Literature
• ZAMAN, Najamuz, 2015. *Automotive electronics design fundamentals* [online]. Cham [u.a.]: Springer. PDF e-Book. ISBN 978-3-319-17584-3. Available via: https://doi.org/10.1007/978-3-319-17584-3. • IDA, Nathan, 2021. *Engineering Electromagnetics* [online]. Cham: Springer International Publishing. PDF e-Book. ISBN 978-3-030-15557-5. Available via: https://doi.org/10.1007/978-3-030-15557-5.
Additional remarks
None

Principles of Flight Mechanics, Flight Systems and Platforms

Module abbreviation	IAS_PrincplFlightMech	**Reg.-Nr.**	5
Curriculum	**Study Programme**	**Module type**	**Semester**
	Intelligent Aerial Systems	Compulsory Subject	1
Module frequency	winter and summer term	**Module duration**	1 semester

Responsible for module	Elsbacher, Gerhard		
Lecturer(s)	Elsbacher, Gerhard		
Language of instruction	English	**Language of exams**	English
Credit points / SWS	5 ECTS / 4 SWS		
Workload	Contact hours		47 h
	Self-study		78 h
	Total		125 h
Subjects of the module	Principles of Flight Mechanics, Flight Systems and Platforms		
Lecture types	SU/Ü - lecture with integrated exercises		

Examinations

schrP90 - written exam, 90 minutes

Additional explanations regarding examinations

None

Prerequisites according examination regulation

None

Recommended prerequisites

None

Objectives

Upon completion of the module, students will be able to:

- identify the primary structural components and propulsion systems of a fixed-wing aircraft, explaining the generation of fundamental aerodynamic forces and the aerodynamic drag polar.
- define essential coordinate systems and identify the minimum set of general aircraft states required to mathematically describe and model aircraft behavior.
- apply point-mass equations of motion to calculate steady-state and maneuvering flight performance metrics, including climb rates, turn radii, and load factors.
- evaluate thrust and power requirements to calculate maximum range, endurance, and operational limits (flight envelope) for fixed-wing configurations.
- explain the concepts of static and dynamic stability, and interpret given linear state-space models to describe standard longitudinal and lateral-directional eigenmodes of fixed-wing aircraft.
- summarize the fundamental mechanical and aerodynamic differences between conventional fixed-wing aircraft and multicopter platforms, applying basic rotorcraft principles to estimate hovering efficiency and power requirements.

Content

Part 1: Aviation Fundamentals

- Aircraft Anatomy & Components: Introduction to the basic architecture of fixed-wing aircraft. Overview of primary control surfaces (ailerons, elevators, rudder) and propulsion systems.

- Atmosphere & Airspeed: The Standard Atmosphere (ISA) and the definitions of airspeed (IAS, TAS, GS, Mach number).
- Aerodynamic & Propulsion Forces: Generation of fundamental forces acting on the aircraft (lift, drag, weight, and explicitly thrust/propulsion forces). Introduction to airfoil characteristics, wing geometry, and aerodynamic drag polar.
- Coordinate Systems & Kinematics: Introduction to essential reference frames (e.g., Earth/ECEF, NED, Body).
- General aircraft states: Minimum set of variables to properly define the behavior of an aircraft.

Part 2: Flight Performance (Fixed-Wing)

- Point-Mass Equations of Motion: Conceptual derivation and application of point-mass equations of motion for simplified performance analysis.
- Steady-State Flight Performance: Calculation of flight performance metrics for specific operational phases, including steady climb, descent, and cruise flight.
- Maneuvering Performance: Mechanics of turning flight (steady level turns, load factor, turn radius, and turn rate).
- Advanced Performance & Operational Limits: Analysis of thrust and power available versus required. Calculation methods for maximum flight range and endurance. Defining the flight envelope (V-n diagram, stall, and maximum speeds).

Part 3: Introduction to Flight Dynamics (Fixed-Wing)

- Rigid-Body Dynamics: Transitioning from point-mass kinematics to 6-Degree-of-Freedom (6DoF) rigid-body concepts.
- Static & Dynamic Stability: Fundamentals of longitudinal and lateral-directional static and dynamic stability (e.g., aerodynamic center, center of gravity).
- Linearization & Eigenmodes: High-level conceptual overview of trimming and linearization. Interpretation of given linear state-space models to analyze and describe typical flight modes (e.g., short period, phugoid, Dutch roll, spiral stability).

Part 4: Multicopter Systems & Outlook

- Multicopter Fundamentals: High-level overview of multirotor platforms, highlighting the fundamental structural, mechanical, and aerodynamic differences compared to conventional fixed-wing aircraft.
- Rotorcraft Principles: Basic principles of multirotor thrust generation, power requirements, and hovering efficiency.
- Outlook: Brief introduction to advanced configurations (e.g., hybrid/VTOL transition aircraft) and future trends in autonomous flight platforms.

Literature

- STEVENS, Brian L., Frank L. LEWIS and Eric N. JOHNSON, 2016. *Aircraft control and simulation: dynamics, controls design, and autonomous systems*. Hoboken, New Jersey: Wiley.
- QUAN, Quan, 2017. *Introduction to multicopter design and control* [online]. Singapore: Springer. PDF e-Book. ISBN 978-981-10-3382-7. Available via: https://doi.org/10.1007/978-981-10-3382-7.
- BRÜNING, Gerhard, Xaver HAFER and Gottfried SACHS, 2006. *Flugleistungen: Grundlagen, Flugzustände, Flugabschnitte*. Berlin [u.a.]: Springer. ISBN 3-540-56960-X, 978-3-540-30447-0

Additional remarks

None

Sensor Systems of Autonomous Flight Systems

Module abbreviation	IAS_SenSys	**Reg.-Nr.**	6
Curriculum	**Study Programme**	**Module type**	**Semester**
	Intelligent Aerial Systems	Compulsory Subject	2,3
Module frequency	only summer term	**Module duration**	1 semester

Responsible for module			
Lecturer(s)			
Language of instruction	English	**Language of exams**	English
Credit points / SWS	5 ECTS / 4 SWS		
Workload	Contact hours		47 h
	Self-study		78 h
	Total		125 h
Subjects of the module	Sensor Systems of Autonomous Flight Systems		
Lecture types	SU/Ü - lecture with integrated exercises		

Examinations

schrP90 - written exam, 90 minutes

Additional explanations regarding examinations

None

Prerequisites according examination regulation

None

Recommended prerequisites

None

Objectives

Upon completion of the module, students will be able to

- explain the operating principles of aerial sensor systems
- understand IMU error sources
- analyze inertial measurements for motion estimation
- interpret sensor data for navigation and stabilization
- compare standalone GNSS with integrated navigation solutions
- model sensor uncertainty and noise statistically

Content

- Sensor principles: IMU (accelerometers, gyroscopes, magnetometers), GNSS receivers, air data sensors (Pitot tubes, flow sensors)
- Perception sensors: RGB and global-shutter cameras, stereo and multi-view vision, event cameras, LiDAR (mechanical, solid-state, flash), ToF (time of flight), radar and mmWave sensors
- Concepts of sensor fusion: noise models, uncertainty (aleatoric and epistemic), covariance, synchronization, calibration and alignment, multi-rate fusion strategies

Literature

Will be specified at the beginning

Additional remarks
None

Navigation and Localization

Module abbreviation	IAS_NavLoc	**Reg.-Nr.**	7
Curriculum	**Study Programme**	**Module type**	**Semester**
	Intelligent Aerial Systems	Compulsory Subject	2,3
Module frequency	only summer term	**Module duration**	1 semester

Responsible for module	Salamat, Babak		
Lecturer(s)			
Language of instruction	English	**Language of exams**	English
Credit points / SWS	5 ECTS / 4 SWS		
Workload	Contact hours Self-study Total		47 h 78 h 125 h
Subjects of the module	Navigation and Localization		
Lecture types	SU/Ü - lecture with integrated exercises		

Examinations

schrP90 - written exam, 90 minutes

Additional explanations regarding examinations

None

Prerequisites according examination regulation

None

Recommended prerequisites

None

Objectives

Upon completion of the module, students will be able to

- define, transform, and interpret coordinate systems used in aviation and to represent orientation by means of different methods.
- implement and analyze strapdown inertial navigation systems (SINS), including integration of angular rate and acceleration data to estimate attitude, velocity, and position in real time.
- distinguish between absolute state estimation and error-state estimation, and in applying Kalman filtering to improve navigation accuracy in the presence of sensor noise and drift.
- use optical flow and visual odometry techniques to estimate motion from camera data, and to fuse this information with inertial measurements for robust navigation in GPS-denied environments.
- apply AI-assisted methods (e.g., deep learning for visual feature extraction, neural networks for sensor fusion) to enhance localization accuracy, robustness, and adaptability in complex or dynamic environments.

Content

- coordinate systems in aviation
- rotation matrices
- representation of the orientation of aviation systems in three-dimensional space: Euler angles, DCM, and the gimbal lock phenomenon, quaternions
- strapdown navigation algorithms

- estimation of absolute navigation state vs. error state estimators in combination with strapdown navigation
- optical flow / visual odometry
- Simultaneous Localization and Mapping (SLAM)
- AI-assisted localization

Literature

- JEKELI, Christopher, 2023. *Inertial Navigation Systems with Geodetic Applications* [online]. Berlin ; Boston: De Gruyter. PDF e-Book. ISBN 978-3-11-078432-9. Available via: https://doi.org/10.1515/9783110784329.
- CONWAY, Richard, 2026. *Introduction to Rotations in Three Dimensions for Engineers and Scientists* [online]. Cham: Springer Nature Switzerland. PDF e-Book. ISBN 978-3-032-05014-4. Available via: https://doi.org/10.1007/978-3-032-05014-4.
- KOUBAA, Anis, AZAR, Ahmad Taher, 2021. *Deep Learning for Unmanned Systems* [online]. Cham: Springer International Publishing. PDF e-Book. ISBN 978-3-030-77939-9. Available via: https://doi.org/10.1007/978-3-030-77939-9.
- GROVES, Paul D., 2013. *Principles of GNSS, inertial, and multisensor integrated navigation systems*. Boston, Mass. [u.a.]: Artech House. ISBN 978-1-60807-005-3
- GREWAL, Mohinder S., ANDREWS, Angus P., BARTONE, Chris G., 2020. *Global navigation satellite systems, inertial navigation, and integration* [online]. Hoboken, NJ: Wiley. PDF e-Book. ISBN 978-1-119-54784-6, 978-1-119-54781-5. Available via: https://onlinelibrary.wiley.com/doi/book/10.1002/9781119547860.

Additional remarks

None

Software-Architectures and Model-based Systems Engineering

Module abbreviation	IAS_SWArchSysEng	Reg.-Nr.	8
Curriculum	**Study Programme**	**Module type**	**Semester**
	Intelligent Aerial Systems	Compulsory Subject	
Module frequency	only summer term	Module duration	1 semester

Responsible for module	Schwerd, Simon		
Lecturer(s)			
Language of instruction	English	**Language of exams**	English
Credit points / SWS	10 ECTS / 0 SWS		
Workload	Contact hours Self-study Total		70 h 180 h 250 h
Subjects of the module	8.1: Software-Architectures and Model-based Systems Engineering 8.2: Practical Lab SW-Architectures and MBSE		
Lecture types	8.1: SU/Ü - lecture with integrated exercises 8.2: Pr - laboratory		

Examinations

8.1: schrP90 - written exam, 90 minutes
8.2: LN - participation without/with success

Additional explanations regarding examinations

None

Prerequisites according examination regulation

None

Recommended prerequisites

Principles of Programming and Software Engineering

Objectives

Upon completion of the module, students will be able to

- distinguish between functional and non-functional requirements in the context of UAV systems, and explain their impact on system design and certification
- explain the principles of Model-Based Systems Engineering (MBSE), their main diagram types (e.g. Block Definition Diagram, Activitiy Diagrams) and justify its application to different stages of the development process of cyber-physical systems
- design the functional, logical and physical architectures of complex cyber-physical systems and justifying the partitioning based on performance, safety, and cost criteria.
- create software architectures for UAV systems based on good software engineering practices
- develop software that integrate with established frameworks and architectures for UAV systems
- evaulate software development processes given regulatory compliance of aerial systems
- define test concepts on varying levels (unit test, integration test, software/hardware-in-the-loop).

Content

- Requirement Engineering: Functional vs. Non-Functional Requirements for UAV Systems

• Model-Based Systems Engineering: Core Languages and Standards (SysML), System Architecture for UAVs: Hardware/Software Co-Design for Flight Systems • HW/SW-Architectures for UAVs: Flight Computers, Payload Computers, Sensor and Actuator Integration • Middleware abstractions and communication protocols (MAVLink, DDS) • Software architecture patterns for cyber-physical systems, e.g. Publish/Subscribe, layered architecture (perception, planning, control, mission management) • Testing Frameworks for Software/Hardware-in-the-loop
Literature
Will be specified at the beginning
Additional remarks
None

Environment Detection and Object tracking

Module abbreviation	IAS_EnvDetect	**Reg.-Nr.**	9
Curriculum	**Study Programme**	**Module type**	**Semester**
	Intelligent Aerial Systems	Compulsory Subject	2,3
Module frequency	only winter term	**Module duration**	1 semester

Responsible for module	Seidel, Christian		
Lecturer(s)			
Language of instruction	English	**Language of exams**	English
Credit points / SWS	5 ECTS / 4 SWS		
Workload	Contact hours Self-study Total		47 h 78 h 125 h
Subjects of the module	Environment Detection and Object tracking		
Lecture types	SU/Ü - lecture with integrated exercises		

Examinations

schrP90 - written exam, 90 minutes

Additional explanations regarding examinations

None

Prerequisites according examination regulation

None

Recommended prerequisites

None

Objectives

Upon completion of the module, students will be able to

- explain the operating principles and performance characteristics of LiDAR, radar, and camera-based sensing modalities for UAV environmental perception, and select appropriate sensor configurations for given operational scenarios and environmental conditions.
- design and implement 3D mapping pipelines for UAVs, including point cloud processing, occupancy grid generation, and map updating strategies for dynamic environments.
- apply deep learning methods — in particular semantic segmentation architectures — to interpret aerial sensor data, and critically evaluate their accuracy, computational cost, and suitability for embedded, real-time deployment on UAV platforms.
- implement and compare classical probabilistic object tracking algorithms (Kalman filter, JPDA, MHT) and image-based optical flow methods (Lucas–Kanade), analysing their assumptions, failure modes, and computational requirements.
- design and evaluate deep learning-based tracking systems using Siamese Networks and multi-object tracking frameworks (SORT, DeepSORT), assessing their robustness under challenging conditions such as occlusion, clutter, and appearance variation.
- realize and validate contrastive learning approaches to allow for dynamic adaption to novel situations.

Content
• Environmental perception: Obstacle detection using LiDAR, ToF, radar, and image processing; 3D mapping and generation of occupancy grids; 3D Gaussian splatting[SM1] ; instance and semantic segmentation (deep learning) • Object tracking: Classical tracking (Kalman filter, JPDA, MHT); image-based tracking (Lucas–Kanade, optical flow), Deep learning-based tracking (Siamese Networks, SORT/DeepSORT), Deep learning-based optical flow estimation • Multi-target tracking: situational awareness, scene prediction, and dynamic environment modeling; detection and avoidance (DAA) algorithms; collaborative perception among multiple UAVs
Literature
• SZELISKI, Richard, 2022. *Computer vision: algorithms and applications* [online]. Cham, Switzerland: Springer. PDF e-Book. ISBN 978-3-030-34372-9. Available via: https://doi.org/10.1007/978-3-030-34372-9. • MURPHY, Kevin P., c2012. *Machine learning: a probabilistic perspective*. Cambridge, MA: MIT Press. ISBN 978-0-262-30524-2 • THRUN, Sebastian, Wolfram BURGARD and Dieter FOX, 2006. *Probabilistic Robotics*. Cambridge, Massachusetts ; London, England: MIT Press. ISBN 978-0-262-30380-4 • GOODFELLOW, Ian, Yoshua BENGIO and Aaron COURVILLE, 2023. *Deep Learning*. [Erscheinungsort nicht ermittelbar]: [Alanna Maldonado]. ISBN 978-973-23-4552-8
Additional remarks
None

Certification and Safety

Module abbreviation	IAS_CertSaf	**Reg.-Nr.**	10
Curriculum	**Study Programme**	**Module type**	**Semester**
	Intelligent Aerial Systems	Compulsory Subject	2,3
Module frequency	only winter term	**Module duration**	1 semester

Responsible for module	Hagerer, Andreas		
Lecturer(s)			
Language of instruction	English	**Language of exams**	English
Credit points / SWS	5 ECTS / 4 SWS		
Workload	Contact hours		47 h
	Self-study		78 h
	Total		125 h
Subjects of the module	Certification and Safety		
Lecture types	SU/Ü - lecture with integrated exercises		

Examinations

mdlP - oral exam, 15-20 minutes

Additional explanations regarding examinations

None

Prerequisites according examination regulation

None

Recommended prerequisites

None

Objectives

Upon completion of the module, students will be able to

- interpret and apply the current EASA and FAA regulatory frameworks for UAV operations, including category classifications, operational authorisation processes, and the implications of evolving regulations for UAV system design and deployment.
- conduct structured hazard identification and risk classification for UAV systems, applying standard taxonomies and severity/likelihood matrices to derive safety objectives consistent with regulatory acceptance criteria.
- distinguish between functional safety and system safety as complementary engineering disciplines, and allocate safety requirements appropriately across hardware, software, and operational procedures within a UAV system architecture.
- explain the software and hardware certification processes applicable to airborne systems — in particular DO-178C and DO-254 — including the role of Development Assurance Levels (DAL), the structure of certification evidence, and the relationship between design, verification, and certification artefacts.
- establish and maintain requirements traceability across the development lifecycle of a safety-critical UAV system, demonstrating how traceability supports both verification completeness and regulatory compliance.
- evaluate the overall certification readiness of a UAV system or subsystem by systematically assessing the completeness and consistency of its safety case, identifying gaps in evidence and proposing remediation strategies aligned with regulatory expectations.

Content
Part 1: Foundations & Regulatory Context • Legal framework and involved authorities (e.g., EASA, FAA) • Aviation regulatory framework with a specific focus on UAV categories and regulations • SORA (Specific Operations Risk Assessment) & SAIL (Specific Assurance and Integrity Level) • Mathematical preliminaries for safety engineering (probability theory, reliability metrics) Part 2: Systems Engineering & Safety Assessment • Integration of requirements engineering within the safety assessment process (e.g., ARP4754B, ARP4761A) • Fundamental safety concepts: Hazard identification, risk classification, and mitigation • Distinguishing functional safety from system safety • Core safety analysis methods: FMEA (Failure Mode and Effects Analysis) and FTA (Fault Tree Analysis) • The bridge to implementation: FHA (Functional Hazard Analysis) and PSSA (Preliminary System Safety Assessment) Part 3: Implementation & Certification • Development processes for safety-critical systems • Certification processes for software and hardware: Design Assurance Levels (DAL), the V-Model, and core industry standards (DO-178C, DO-254) • Establishing rigorous traceability, verification methodologies (e.g., testing, coverage, formal methods), and coding standards Part 4: Autonomy & Advanced topics • Current challenges and emerging concepts for the certification of Machine Learning components and highly autonomous systems (e.g., EASA AI Roadmap)
Literature
• KRITZINGER, Duane, 2017. *Aircraft system safety: assessments for initial airworthiness certification*. Duxford, United Kingdom: Woodhead Publishing is an imprint of Elsevier. ISBN 978-0-08-100932-1, 0-08-100932-1 • RIERSON, Leanna, 2013. *Developing safety-critical software: a practical guide for aviation software and DO-178C compliance*. Boca Raton [u.a.]: CRC Press. ISBN 978-1-439-81368-3
Additional remarks
None

Flight Control, Guidance, Flight Path and Trajectory Planning

Module abbreviation	IAS_FlghtCtrl	**Reg.-Nr.**	11
Curriculum	**Study Programme**	**Module type**	**Semester**
	Intelligent Aerial Systems	Compulsory Subject	
Module frequency	only winter term	**Module duration**	1 semester

Responsible for module	Kefferpütz, Klaus		
Lecturer(s)			
Language of instruction	English	**Language of exams**	English
Credit points / SWS	10 ECTS / 0 SWS		
Workload	Contact hours Self-study Total		70 h 180 h 250 h
Subjects of the module	11.1: Flight Control, Guidance, Flight Path and Trajectory Planning 11.2: Practical Lab Flight Control and Trajectory Planning		
Lecture types	11.1: SU/Ü - lecture with integrated exercises 11.2: Pr - laboratory		

Examinations

11.1: schrP90 - written exam, 90 minutes
11.2: LN - participation without/with success

Additional explanations regarding examinations

None

Prerequisites according examination regulation

None

Recommended prerequisites

None

Objectives

Upon completion of the module, students will be able to

1. derive and analyse the equations of motion for fixed-wing and rotary-wing UAVs, applying linearisation techniques to characterise flight envelope dynamics and identify operating points relevant to control design.
2. design, tune, and evaluate classical PI/PID flight controllers for UAV attitude, velocity, and position loops to meet specified stability margins and dynamic performance requirements.
3. apply methods for UAV motion planning in dynamic, obstacle-rich environments
4. design and evaluate real-time Model Predictive Control (MPC) formulations for UAV trajectory optimisation, incorporating risk-aware planning objectives, probabilistic safety constraints, and corridor-based flight envelope restrictions
5. apply safeguarding strategies by means of control barrier functions and reachibility analysis
6. design and simulate swarm control algorithms for multi-UAV systems, including emergent swarm behaviours and explicit formation control strategies, evaluating their scalability, robustness and communication requirements.

Content

- Equations of Motion for Aircraft

- Classical Flight Control (PI/PID) and Its Design
- Gain-Scheduling Controllers and Inversion-Based Controllers (NDI)
- Motion Planners for Aerospace Applications
- Kinematic and dynamic feasibility constraints
- Real-time MPC-based trajectory generation and optimization
- Risk-aware and safe planning (random constraints, safety corridors)
- Safeguarding trajectory planners
- Swarm Control Algorithms (Swarm Behavior, Formation Control)

Literature

- STEVENS, Brian L. , Frank L. LEWIS and Eric N. JOHNSON, 2016. *Aircraft Control and Simulation: Dynamics, Controls Design, and Autonomous Systems*. [s.l.]: John Wiley & Sons.
- CHAI , Runqi, Kaiyuan CHEN and Lingguo CUI, 2023. *Advanced Trajectory Optimization, Guidance and Control Strategies for Aerospace Vehicles* . [s.l.]: Springer.
- KOUVARITAKIS, Basil and Mark CANNON, 2023. *Model Predictive Control* . [s.l.]: Springer Singapore.
- SINHA, Nandan K. and N. ANANTHKRISHNAN , 2017. *Advanced Flight Dynamics with Elements of Flight Control*. [s.l.]: CRC Press.
- ZHAO , Guanglei , Hailong CUI and Changchun HU, 2024. *Cooperative Control of Multi-Agent Systems* . [s.l.]: Springer.

Additional remarks

None

Master Thesis

Module abbreviation	IAS_MasterThesis	**Reg.-Nr.**	15
Curriculum	**Study Programme**	**Module type**	**Semester**
	Intelligent Aerial Systems	Compulsory Subject	
Module frequency	winter and summer term	**Module duration**	1 semester

Responsible for module	Hagerer, Andreas		
Lecturer(s)			
Language of instruction	English	**Language of exams**	English
Credit points / SWS	30 ECTS / 0 SWS		
Workload	Contact hours Self-study Total		0 h 750 h 750 h
Subjects of the module	15.1: Master Thesis 15.2: Master Thesis Colloquium		
Lecture types	15.1: MA - Master's Thesis 15.2: S - seminar		

Examinations

15.1: Master-Thesis
15.2: Colloquium

Additional explanations regarding examinations

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

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

Prerequisites according examination regulation

None

Recommended prerequisites

None

Objectives

Upon successful completion of the master’s thesis and its colloquium, students will be able to:

- Independently address a complex engineering problem from the study program's subject area within a defined timeframe and, if applicable, a specified budget, using scientifically sound methods.
- Systematically and creatively develop solutions to similar or related problems.
- Identify and critically evaluate the limitations of the developed solution.
- Clearly define the problem, contextualise it within a broader framework, and present and discuss the solution and results in accordance with scientific writing standards (e.g., coherence, transparency) and formal academic criteria.
- Adhere to principles of good scientific practice and apply appropriate scientific research methods.

- Present the core content of their master thesis in a clear and comprehensible manner within a given time frame.
- Position their own scientific work in the existing knowledge environment.
- Carry out a scientific discussion with a critical audience.

Content

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

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

In the colloquium the student presents the problem, approaches, solution and limits of the theses' topic and discusses them with fellow students and the lecturers.

Literature

- PRUZAN, Peter, 2016. *Research methodology: the aims, practices and ethics of science*. [Cham]: Springer. ISBN 978-3-319-27166-8, 978-3-319-80084-4
- TURNER, Kathy, 2011. *Essential academic skills*. Oxford: Oxford Univ. Press. ISBN 978-0-19-557605-4, 0-19-557605-5
- SWALES, John and Christine B. FEAK, 2012. *Academic writing for graduate students: essential tasks and skills*. Ann Arbor: Univ. of Michigan Press. ISBN 978-0-472-03475-8

Additional remarks

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

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

Note, in case of a Dual Study, the Master's Thesis must be completed with the cooperating company.