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Fakultät für Ingenieurwesen
Facoltà di Ingegneria
Faculty of Engineering

COURSE DESCRIPTION – ACADEMIC YEAR 2023/2024

Course title	**Systems Engineering for the Design of Cyber-Physical Systems**
Course code	46062
Scientific sector	Ing-Ind/16 + Ing-Inf/05
Degree	PhD in Advanced Systems Engineering
Semester	1
Year	2023-24
Credits	3

Total lecturing hours	Part 1: 15h + Part 2: 15h
Attendance	The course will be offered in person.
Prerequisites	/
Specific educational objectives	The course provides the methodological basis for the design of complex systems focusing in the practical part on cyber-physical systems. In the **first part** students learn to apply **Systems Engineering** for the design of systems like products, machines, software as well as large and complex systems. In specific the courses combines Systems Engineering approaches with Axiomatic Design theory. User needs are translated into technical language in sense of functional requirements, which afterwards are translated into potential design solutions. Using the independence and information axiom the design solutions are decomposed top-down from an abstract and conceptual level into more tangible solutions. Those design solutions are then used for further developing the design of a cyber-physical system using Model-Based Systems Engineering (MBSE) software. By building an idea, designers are challenged to "build to think" and thus gain deeper insights. The **second part** of this course will go beyond early physical **prototyping** and show how to implement smart sensing devices that can be used to control an interactive environment (e.g. game). Participants will learn basic electronics, microcontroller programming, and physical prototyping using the Arduino/ESP32 platform, then use digital and analog sensors which results in a next-generation controller.

Lecturer(s)	Part 1) Prof. Erwin Rauch, Dr. Ali Asghar Bataleblu Part 2) Prof. Michael Haller
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Scientific sector of lecturer(s)	Part 1) Ing-Ind/16 Part 2) Ing-Inf/05

Teaching language	English
Office hours	*Upon appointment*
Lecturing Assistant (if any)	/
Contact LA	/
List of topics	**Part 1) Systems Engineering** An introduction to the hard and soft skills required for systems engineers. Lectures follow the competency models for systems engineers and include topics such as systems thinking, needs identification, requirements formulation, architecture definition, technical management, and verification and validation of designs. Some key systems engineering (SE) procedures like Axiomatic Design (AD) and Requirements Writing rules using Model-based Systems Engineering (MBSE) tools will be covered and the roles of organizations in enabling engineers to develop systems will be explored. Applications of SE concepts and tools in various settings will be discussed through examples and case studies. Students will learn to apply the SE methodologies in modern complex system development environments such as mechatronics, aerospace and aviation, transportation, energy, communications, and modern software-intensive systems Content: • Systems Engineering Overview • System Architecting and Uncertainty-based Multidisciplinary Systems Design • Introduction to Axiomatic Design, Customer Needs, Functional Requirements, and Design Parameters • Decomposition and Mapping Process and Teamwork Projects Description • Requirements Writing and Verification and Validation • System Modeling Language (SysML) • Model-based Systems Engineering with Cameo System Modeler • Teamwork/Project-work A project is to be developed by each group of students, which is expected to evolve during the entirety of the semester. The project will entail applying a model-based system engineering tool (Cameo) for the AD of a product or system considered. Students will present the result of their project on Axiomatic Design with the application of MBSE. Each project should be presented in 15 minutes as part of a one-hour final lecture **Part 2) Prototyping** Building an idea, designers are challenged to "build to think" and thus gain deeper insights. This course will go beyond early physical prototyping and show how to implement smart sensing devices that can be used to control an interactive environment (e.g. game). Participants will learn basic electronics, microcontroller programming, and physical prototyping using the Arduino/ESP32 platform, then use digital and analog sensors which results in a next-generation controller, e.g. in combination with Unity. Therefore, students will gain

	a profound understanding of sensor technologies as well as a broad overview of how to design and implement a 3d environment. Each student group is provided with a physical computing kit including an Arduino/ESP32 compatible board as well as everything needed to learn how to use sensors and actuators and how to combine it with 3rd party tools (e.g. Unity). Through hands-on experiences during class periods, students acquire basic skills and learn to build a range of typical circuits that will communicate to Unity. Along with basic skill acquisition, students are involved in a group assignment in which they develop a complex project from start to finish. Students are encouraged to quickly arrive at a working prototype at which point they can fine-tune their project through testing. At the end of the semester, the projects are presented to the rest of the class. Content: • Design physical mockups with a focus on next-generation interfaces • New hardware trends (e.g., Embedded Processors, Miniaturized Sensors, • New Materials, Ubiquitous Computing Characteristics, and Systems) • Sensors (focusing on Arduino IDE) • Ideate, design, and implement a smart controller
Teaching format	Frontal lectures, Exercises, Teamwork Projects

Learning outcomes	Knowledge and understanding: • Think as a system and boost mindset to multidisciplinary and collaborative thinking • Develop requirements, architectures, specifications, verifications, and tests. • Analyze systems using model-based systems engineering tools. Applying knowledge and understanding: • Decompose a problem to different levels of functional requirements and physical solutions. • Apply systems engineering practices and methods to relevant examples. • Apply the learned methods using commonly used software Making judgments • Ability to select and decide about design alternatives and solutions Communication skills • Describe processes, methods, and practices of systems engineering. • Explain and present technical and complex content in English language in front of audience Learning skills • Deal with problems in a systematic and creative way and to appropriate problem solving techniques. • Define a problem or project right based on stakeholders' needs.

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Assessment	Part I: Written test and project work Part II: Oral test about the final project
Assessment language	English
Assessment Typology	Non monocratic
Evaluation criteria and criteria for awarding marks	Student grades will be based on the average between Part I and Part II. For Part I the grade is based on the results of a written exam (50%), and a project work (50%). For Part II: Each student group is provided with a physical computing kit including an Arduino/ESP32 compatible board as well as everything needed to learn how to use sensors and actuators and how to combine it with 3rd party tools (e.g. Unity). Through hands-on experiences during class periods, students acquire basic skills and learn to build a range of typical circuits that will communicate to Unity. Along with basic skill acquisition, students are involved in a group assignment in which they develop a complex project from start to finish. Students are encouraged to quickly arrive at a working prototype at which point they can fine-tune their project through testing. At the end of part II, the projects are presented to the rest of the class.

Required readings	Lecture notes for Part 1 will be distributed and made available online. All the lecture notes, samples etc. of Part 2 can be found in the TEAMS folder.
Supplementary readings	1- NASA Systems Engineering Handbook, 2018. 2- Guide to Writing Requirements, INCOSE, 2023 3- Requirements writing pdf, Michael Ryan 4- MagicGrid Book of Knowledge, A Practical Guide to Systems Modeling using MagicGrid, https://discover.3ds.com/magicgrid-book-of-knowledge
Software used	1- Miro | The Visual Workspace for Innovation, https://miro.com 2- Magic Systems of Systems Architect, CATIA Magic | Dassault Systèmes, https://www.3ds.com/products/catia/catia-magic 3- Different microcontrollers and microelectronics kits are used. Only participant students, who attend classes, can use them during class time. Moreover, we will mainly use ProtoPie, Visual Studio Code, Unity and the Arduino IDE, all of which are available for the students. Further information is provided are on the course web page