Major in Internet of Things

A Specialisation within the Master's Degree Programme in Information and Computer Engineering (ICE)

The Key Researchers of the Dependable Things Project
Graz University of Technology

January 2021

This document extends and refers to the official "Curriculum for the master's degree programme in Information and Computer Engineering" (ICE) from 2015, version 2020.

1 Introduction

Internet of Things. A new tier is being added to the Internet, consisting of networked computing devices that are embedded into arbitrary *things*. These devices are equipped with sensors to perceive signals from the surrounding environment and processing capabilities to infer their own state and that of the environment. The devices share information using wireless communication and jointly derive a reaction by triggering actuators that physically influence the environment. By 2030, 50 billion of such smart things will be connected to the Internet – outweighing by far the number of general purpose computers and smart phones. The resulting Internet of Things (IoT) will be one of the 10 most disruptive technologies in the coming decade and will continue to have a transformational impact on society.

In fact, the IoT will become a global super-infrastructure as it is a key enabling technology that provides services for application domains with very high societal relevance and impact. This includes smart cities that monitor and optimise the use of resources; smart cars that communicate with each other and with the road infrastructure; smart health, where patients are monitored; smart factories, where production processes are controlled or optimised; and smart buildings that maximise the comfort of their inhabitants by adapting light, sound, climate, etc.

IoT Research at TU Graz. The described application domains require a highly dependable IoT, that works correctly in any situation and under all circumstances. *Dependability* comprises aspects such as reactivity, safety, security, and maintainability, that allow users to put trust into the IoT. However, today's approaches to construct the IoT or its components do not sufficiently guarantee dependability. The research centre *Dependable Internet of Things* thus brings together eleven of the best researchers from the departments of Computer Science & Biomedical Engineering and Electrical & Information Engineering at TU Graz in order to work on scientific foundations for an IoT that works dependably and that is resilient against failures and attacks.

IoT Education at TU Graz. Complementing this research on the IoT, TU Graz has designed a course catalogue to allow master students a specialisation in related topics. The catalogue is subdivided into eleven "areas" – one per key researcher. It is part of the well-established master's degree programme in *Information and Computer Engineering (ICE)* and can be selected as a "major" according to the official curriculum.

2 Master's Degree Programme in ICE

Students of the the master's degree programme Information and Computer Engineering (ICE) at TU Graz work with internationally renowned scientists and teams from industry and research on technologies of the future. The duration is four semesters and the courses are taught in English. Details can be found in the official curriculum.

Content summary. ICE students study the central theories, principles, and concepts of computer science, information processing, information technology, and electrical engineering. They attend lectures, exercises, labs, and projects to learn scientific methods and apply them. They work with fellow students and in international teams from industry and academia. They also have the opportunity to temporarily leave TU Graz for a semester abroad, allowing them to meet renown researchers and complement their degree programme, that ends with the master's thesis. With the support of a mentor, the students specialise in two fields in the form of one major and one minor.

3 The Major in IoT

The rules for choosing the Major in IoT are consistent with the ICE master's programme and have been approved by the mentors and the Dean of Studies. Thus, the curriculum for the "Master in ICE" applies in general, unless special regulations are specified in this document for the "Major in Internet of Things".

Structure. According to §4 of the curriculum, the ICE Master with a specialisation in IoT consists of:

1. the **Major in Internet of Things** with at least 40 ECTS credit points,
2. a **minor** with at least 20 ECTS credit points.

   The minor follows the standard ICE master and can be selected from the catalogues of free electives defined in §5a of the curriculum.
3. an **elective subject** that contains courses with a workload of up to 14 ECTS points. The courses are to be selected from the list in §5a of the ICE curriculum in such a way that the total for the major, minor and elective subject comprises at least 74 ECTS credit points, and a higher number of ECTS points from Items 1 and 2 reduces the required number of ECTS points from the elective subject.
4. a **seminar/project** with a workload of 10 ECTS points, which is assignable to the major or the minor;
5. a **free-choice subject** that contains free-choice courses with a workload of 6 ECTS credit points
6. a **master's thesis**. The master's thesis corresponds to 30 ECTS points and must be assignable to a technical subject according to the ICE curriculum.

Compiling and passing the Major in IoT. The rules for compiling the Major in IoT are as follows:

1. During the first semester of the ICE master's degree programme, the selection of electives for the major and minor must be stated.
2. For the Major in IoT, students have to select three out of eleven areas from Section 4. In order to qualify for a major, the total workload for the selected areas must be at least 40 ECTS credits. All courses in all chosen areas must be successfully completed in order to succeed. Achieved ECTS points above 40 can be credited as free-choice subjects.
3. Ensure the "balance" according to §4.4 of the ICE curriculum: across the items 1-5 listed in the structure above, at least 18 ECTS credits must be completed in the field of "electrical and information engineering", and at least 18 ECTS credits in "information processing".
4. Each area has a responsible mentor. It is recommended to select the personal mentor from the selected areas.

4 Areas in IoT

The Major in IoT within the Master in ICE provides a fixed set of so called "Areas" to specialise in. These areas are described below and for each one, a table shows the name of the courses, the semester hours (SH), the type of course (CT), and the ECTS credits for the master's degree programme in ICE.

A1. Advanced Testing Techniques

Name of the Course	SH	CT	ECTS
Formal Specification and Design of Software	3	VU	5
Model-Based Testing	3	VU	5
Software-Maintenance	3	VU	4.5
Total ECTS			**14.5**

Content: This area covers the foundations, techniques and methods in order to further automate the testing process with a special focus on automated test-case generation. Topics include the specification and modelling of systems, symbolic execution, property-based testing, model-based testing, mutation testing, and learning-based testing. In addition, advanced debugging techniques, like slicing and data-flow analysis will be introduced.

Objectives: The students will have a good overview of the state-of-the-art and the ongoing research in advanced testing techniques. They will know the foundations, techniques and a number of selected tools in order to automate the testing process. In addition, the students will have a better understanding of how to abstract from implementation details while still being precise and know how to specify systems.

Previous knowledge expected: Basic knowledge in discrete mathematics and software engineering is expected.

Mentor: Bernhard Aichernig, Institute of Software Technology

Field (balance): information processing

A2. Control Theory

Name of the Course	SH	CT	ECTS
Basics of Nonlinear Control Systems	2	VO	3
Basics of Nonlinear Control Systems	1	UE	2
Nonlinear Control Systems	2	VO	3
Nonlinear Control Systems	1	UE	2
State Estimation and Filtering	2	VO	3
State Estimation and Filtering	1	UE	2
Total ECTS			**15**

Content: The area *control theory* offers selected courses indispensable for understanding advanced control techniques for IoT applications. Important topics like nonlinear control and estimation theory are covered.

Objectives: The students will gain knowledge on analysis and design of nonlinear systems and on the basics of estimation theory. They will understand important concepts from system theory which form the basis of advanced techniques in control engineering.

Previous knowledge expected: Basic knowledge in linear system theory and control engineering.

Mentor: Martin Horn, Institute of Automation and Control

Field (balance): electrical and information engineering

A3. Deeply Embedded Systems

Name of the Course	SH	CT	ECTS
Real-Time Operating Systems	2	VO	3
Real-Time Operating Systems	1	LU	1.5
Processor Architecture	2	VO	3
Processor Architecture	1	LU	1.5
MCU Design Lab	4	LU	6
Total ECTS			**15.0**

Content: This area gives deep insight on the complex interactions between embedded real-time operating systems (RTOS) and micro controller (MCU) architectures. Besides conveying foundations of OS kernels (e.g., internal data structures and algorithms, inter-process-communication, resource management under real-time conditions, etc.) and MCU cores (e.g., instruction set concepts, pipelining, interrupt handling, bus I/O, etc.), practical exercises comprise the implementation of a basic RTOS kernel (mainly in C) and a MCU core (mainly in VHDL).

Objectives: The students will receive an overview of the state-of-the-art and ongoing research in RTOS and MCU architectures for future embedded systems, e.g., within the Internet of Things or for autonomous vehicles. They will learn foundations, advanced techniques, and design patterns in the lectures and apply related languages and tools for realizing software and hardware at low system levels in the labs. Eventually, the students will have a better understanding of the tight interactions along the entire hardware/software stack, and are able to better assess the consequences of certain implementation strategies on the overall system dependability.

Previous knowledge expected: Basic knowledge in algorithms & data structures and computer architecture (for the lectures) and on low-level programming and hardware description languages (for the labs) would be helpful.

Mentor: Marcel Baunach, Institute of Technical Informatics

Field (balance): electrical and information engineering

A4. Formal Verification

Name of the Course	SH	CT	ECTS
Model Checking	2	VO	3
Model Checking	1	UE	2
Seminar Formal Methods	2	SE	3.5
Verification and Testing	2	VO	3
Verification and Testing	1	UE	2
Total ECTS			**13.5**

Content: This area covers formal verification as a way to find bugs or to prove that a hardware or software system is correct. We teach logics, their application, and the algorithms to decide whether logical formulas are correct. We give an overview of advanced testing and verification techniques including testing of concurrent programs, static analysis, and model checking. We also introduce synthesis as a method to automatically construct (portions of) a program according to a specification.

Objectives: Students will receive a thorough introduction to the algorithmic aspects of logics, an overview of selected verification techniques, and an in-depth understanding of modern methods for automatic programming.

Previous knowledge expected: Basic knowledge of discrete mathematics, interest in the overlap between theoretical and practical aspects of Computer Science.

Mentor: Roderick Bloem, Institute of Applied Information Processing and Communications

Field (balance): information processing

A5. IT Security

Name of the Course	SH	CT	ECTS
Secure Application Design	2	VO	3
Secure Application Design	1	KU	2
Cryptography	2	VO	3
Cryptography	1	KU	2
Side-Channel Security	3	VU	5
Total ECTS			**15**

Content: This area gives an introduction to the IT security challenges in the Internet of Things. The courses cover known attack techniques as well as corresponding countermeasures. In particular, the topics include attacks exploiting memory safety issues, side-channel attacks in software as well as hardware and protection mechanisms against all these types of attacks. Furthermore, a detailed introduction to cryptography is provided. All courses include practicals in order to provide hands-on experience on the security challenges of IoT devices.

Objectives: The students will learn the state-of-the-art cryptographic techniques as well as attack techniques and countermeasures on IoT devices. They will learn theoretical foundations and design methods that are a pre-requisite for the design of secure and efficient IoT devices. An important aspect of this area is to create the awareness of the wide range of attack techniques and the fact that security is an essential system property that needs to be considered from the very beginning of the design process of an IoT device.

Previous knowledge expected: Basic knowledge in operating systems is expected.

Mentor: Stefan Mangard, Institute of Applied Information Processing and Communications

Field (balance): information processing

A6. Machine Learning

Name of the Course	SH	CT	ECTS
Signal Processing and Machine Learning 1, Seminar	2	SE	3.5
Autonomously Learning Systems	2	VO	3
Autonomously Learning Systems	1	KU	2
Computational Intelligence	2	VO	3
Computational Intelligence	1	UE	1.5
Computational Intelligence Seminar A	2	SE	3.5
Total ECTS			**16.5**

Content: The most important concepts and methods from various areas of machine learning and pattern recognition are covered. In particular, the focus is on generalized linear models, probabilistic models, support vector machines and deep neural networks for classification, clustering and regression amongst others. Furthermore, sequence models and data transformations are treated. The methods are applied on data from real-world applications in the practical problem classes.

Objectives: After successful completion the student will have basic knowledge of the state-of-the-art in machine learning, i.e. knowledge of the most important concepts and methods form various areas of machine learning, deep neural networks, statistical modelling and classification.

Previous knowledge expected: Elementary mathematical knowledge in probability theory, statistics, and calculus is necessary in addition to software engineering skills.

Mentor: Franz Pernkopf, Institute of Signal Processing and Speech Communication

Field (balance): electrical and information engineering

A7. Microwave Engineering

Name of the Course	SH	CT	ECTS
Fundamentals of RF and Microwave Engineering	2	VO	3
Fundamentals of RF and Microwave Engineering	1	UE	2
Smart Antennas	2	VU	3.5
Selected Topics on RFID Sensor Systems	2	VO	3
Microwave Measurement Techniques	2	VU	3
Total ECTS			**14.5**

Content: This area provides a general introduction to radio frequency (RF) and microwave engineering, addressing topics like transmission line theory, input impedance and impedance matching, scattering parameters, as well as passive and active elements. In addition, a range of more advanced topics is covered like antenna arrays (phased array and reflectarray antennas), near field communication (NFC), ultra high frequency (UHF) radio-frequency identification (RFID), principles of RF amplifier design, stability of RF amplifiers, measurements of the frequency spectrum of signals and power measurements.

Objectives: After successfully completing the courses, the students understand the fundamental theoretical principles of transmission lines and active and passive microwave components and are capable of applying appropriate simulation and measurement techniques to design and measure these devices.

Previous knowledge expected: Knowledge on matrix calculations and the courses: "Electric Circuits and Multiports" (437.205) and "Communication Engineering" (SES.206UF).

Mentor: Wolfgang Boesch, Institute of Microwave and Photonic Engineering

Field (balance): electrical and information engineering

A8. Signal and Information Processing

Name of the Course	SH	CT	ECTS
Adaptive Systems	2	VO	3
Adaptive Systems	1	UE	1.5
Information Theory and Coding	2	VO	3
Information Theory and Coding	1	UE	1
Nonlinear Signal Processing	2	VO	3
Nonlinear Signal Processing	1	UE	1.5
Total ECTS			**13**

Content: Adaptive systems and algorithms of the LMS type, optimality principles, performance measures, implementation; application to channel equalization in digital communications, adaptive control, and (acoustic) echo cancellation. Nonlinear signal processing as a technology to counteract distortions as well as to create efficient solutions, e.g., in impulse noise filtering. Systematic hierarchy of systems, starting from memoryless to fading memory and non-fading memory (oscillators). Discussion of universal system representations, higher-order signal statistics, and signal processing paradigms. Information theory as introduced by Shannon, channel coding theorems, practical channel codes including turbo codes, (lossless) source coding.

Objectives: Students will know advanced signal processing methods, including their derivation and performance analysis, as applied to automatic learning for dynamical systems and nonlinear systems. This includes the informed choice of system classes and their mathematical representations as well as algorithm development, optimization, and implementation. Furthermore, they will understand and be able to explain the definition and application of information measures for the representation of information sources, how theses measures are used to establish fundamental limits of communication, and they will be well-versed in the application and design of various error correcting codes and (lossless) data compression schemes.

Previous knowledge expected: Basic courses in "Signals and Systems", "Signal Processing", "Introduction to Probability and Stochastic Processes", "Communications".

Mentor: Gernot Kubin, Institute of Signal Processing and Speech Communication

Field (balance): electrical and information engineering

A9. Wireless Communications

Name of the Course	SH	CT	ECTS
Fundamentals of Digital Communications	2	VO	3
Fundamentals of Digital Communications	1	UE	2
Mobile Radio Systems	2	VO	3
Statistical Signal Processing	2	VO	3
Statistical Signal Processing	1	UE	2
Total ECTS			**13**

Content: This area covers the fundamentals of the physical layer of wireless communication systems, that is, the design of transmitter and receiver techniques for the radio links connecting the nodes of the IoT. Signal processing techniques are employed to model the transmitted signals and the essential blocks of the demodulator and detector, aiming at minimizing the probability of transmission errors. Another important aspect is multipath propagation, which addresses the fundamental physical impairment of the radio channel that has to be overcome in order to realize reliable wireless links. Finally, the discussion of existing wireless technologies will demonstrate the actual application of these theoretical insights in practical wireless systems.

Objectives: Students will develop profound insight in the principles of wireless communications, which have enabled the tremendous success of wireless technologies such as GSM, WiFi, 3G, and LTE in recent years. Students will also learn about the value of signal processing techniques for the design and optimization of these systems. Specifically methods from communication theory and statistical signal processing will be in the focus, including signals and systems, random processes, and detection and estimation theory. Students will learn how these methods can be used for engineering wireless communications systems and also other applications, for example localization and tracking systems.

Previous knowledge expected: Basic courses in signal processing, signal transformations, and communications.

Mentor: Klaus Witrisal, Institute of Signal Processing and Speech Communication

Field (balance): electrical and information engineering

A10. Wireless Networking

Name of the Course	SH	CT	ECTS
Embedded Internet	2	VU	3
Embedded Internet	2	LU	3
Sensor Networks	2	VU	3
Context-Aware Computing	2	VO	3
Mobile Computing, Laboratory	2	LU	3.5
Total ECTS			**15.5**

Content: This area covers foundations, methods, experimentation and applications of wireless networking for the Internet of Things. A special focus is on low-power wireless communication technologies including physical layer aspects, medium access control, topology control, routing, up to application-layer protocols and their integration with the Internet. Also fundamental wireless services such as time synchronization and localization as well as self-organization and self-adaption are covered. The area also includes hands-on courses where the students learn to program wireless IoT nodes for a broad range of applications, including for example localization and wireless sensing.

Objectives: The students will have a good overview of the state-of-the-art and the ongoing research in wireless networking for the Internet of Things and will be able to follow the research literature in the area. They will know the foundations, methods and a number of selected tools in order to design, implement, and experiment with wireless networking solutions for the IoT. Students who completed the area have a good grasp of the possibilities and limitations of state-of-the-art wireless communication technologies for the IoT.

Previous knowledge expected: Basic knowledge in networking is expected.

Mentor: Kay Römer, Institute of Technical Informatics

Field (balance): electrical and information engineering

A11. Intelligent Systems

Name of the Course	SH	CT	ECTS
Intelligent Systems	2	VU	3
Intelligent Systems	1	KU	2
Advanced Topics in Artificial Intelligence	2	VO	3
Advanced Topics in Artificial Intelligence	1	UE	2
Advanced Robotics	2	VO	3
Advanced Robotics	1	LU	2
Total ECTS			**15**

Content: The area covers foundations and methods used to automatize the decision making in autonomous intelligent agents and their relation to dependability of the agents' behaviours. The topics include knowledge representation and reasoning, reactive deliberation, various types of planning and execution monitoring. In addition, basic techniques from the robotics domain such as localization, motion planning and object detection as well as control architectures will be covered.

Objectives: The student will gain knowledge about decision making in an intelligent agent or a group of agents and the dependable execution of decisions in a dynamic environment. They will learn the foundations of common representations used for specifying decision making domains and best practices in modelling and solving. In addition, students will have an understanding of the methods used to dispatch the decisions and supervise their execution.

Previous knowledge expected: Basic knowledge in discrete mathematics, logic, control and software engineering is expected.

Mentor: Gerald Steinbauer, Institute of Software Technology

Field (balance): information processing