2018 Master's programme

SYSTEMS, CONTROL AND MECHATRONICS

INTRODUCTION

Technical systems, be they small consumer or medical devices or large production processes, increasingly employ algorithms implemented on computers to give the final product or system the desired properties. Driving factors are e.g. functional and quality demands, energy utilization, environmental demands, or cost reductions.

A striking example of this development can be found in the automotive area – the modern passenger car depends on the integration of the car's mechanical subsystems with a substantial amount of embedded computers, sensors, actuators, and communication devices.

The master's programme *Systems, Control & Mechatronics* addresses the needs emerging from this IT revolution in many branches of industry. Our students shall be able to contribute to the development, leading to the integration of functions for sensing, monitoring and control with products and systems. The strong industrial needs, ranging from small embedded devices to large control systems for production or electric power distribution, are the main motivation for the programme. Swedish industry has a strong tradition in systems engineering and the long-lasting partnership between Chalmers and systems oriented Swedish industry makes Chalmers a perfect choice for students wanting to pursue this rapidly evolving field of engineering.

The aim of the programme is to prepare the students for a professional career by providing a broad systems engineering base, suited for the engineering of complex embedded (computer controlled) products and systems, and offering course packages toward subtopics (e.g. control; automation; mechatronics) and/or fields of application.

PROGRAMME IDEA

A basic idea behind the design of the programme is that the systems perspective and the general systems engineering skills, referred to in the programme aim, are provided by a set of generic methods and tools, which are not tailored to a specific application area or industrial branch. These generic topics form the focus of the programme's compulsory part, and may be further pursued in the course packages offered.

The ***fully compulsory part*** of the programme is comprised of five courses (37.5 hec) during the five first quarters. The intention is that all students should acquire knowledge about computer based control systems, and some of the important phases during development of these. The focus is on the functions building up such systems, and hence the subject areas of control engineering and automation, but important links to computer engineering exist due to the implementation issues involved. The sequence of compulsory courses brings up the following topics:

- Modelling of dynamical systems is covered in the course ***Modelling and simulation (ESS101)***. Modelling and simulation has become a widespread engineering tool for all systems oriented engineering, and the course provides basic tools for systematic modelling from physics and/or experiments. Computer tools introduced are used throughout the programme's courses.
- Modelling of discrete event systems requires its own modelling formalisms and tools and is covered by the course ***Discrete event systems (SSY165)***. The course complements the basically physics driven approach in the previous course with formalisms needed to describe many man-made systems, and in particular systems with logic behaviour often met in production systems.
- The fundamental ideas behind feedback control systems, based upon the triplet sensing – decision – actuation, are pursued in the course ***Linear Control System Design (SSY285)***, which focuses on model based control system design. The course thus naturally builds upon concepts dealt with in the first modelling course, but the course also brings up important aspects on multi variable control, sensing, estimation and digital implementation, the latter directly linking to the course Embedded control systems.
- The course ***Model-based Development of Cyber-Physical Systems (SSY191)*** in the fully compulsory block, introduce the principles of design, specification, modelling, analysis and implementation of cyber-physical systems, for example autonomous vehicles. In this course a structured methodology to specification of requirements, simulation, implementation and realization of the closed-loop system. Cyber-Physcial Systems are by nature often hybrid in the sense that they consists of both discrete and continuous dynamics. This course builds upon the previous courses in modelling and simulation of continuous dynamics and the course in modelling and analysis of discrete event systems and adds knowledge about acasual modelling techniques, e.g. Modelica/Simscape, .
- In the final course in the fully compulsory block, **Design project in systems, control and mechatronics (SSY226)**, a structured project methodology is used in solving a larger design and implementation problem in a team where the skills from the previous

courses are necessary to successfully solve the project. The students should assess the need for scientific information, be able to search for information and critically evaluate its relevance. The students should present their work in a report that properly cites relevant work and patents. The students should also make an oral presentation in front of target groups and give feedback to another project group as well.

Already the compulsory part of the programme contributes to the learning outcomes. A certain familiarity with methods and tools is attained, and the problem solving ability is advanced. Emphasis is given to problem solving and assignments, individually and in small groups, to gain confidence and comprehension. It should be stressed that problem solving will be an important theme throughout the programme, since each student must acquire an individual experience of going from the specific application to the general, abstract concepts, and vice versa. The generic learning skills formulated in the fourth and final set of goals are in general *not* pursued as independent subjects. Rather, these issues are integrated within the courses, so that they are introduced and taught in a *just-in-time* manner; this way, student motivation is improved.

The fully compulsory courses are not sufficient to give the required proficiency and depth in the area for a Master's Degree. Therefore, a number of compulsory elective courses are offered within the programme. The ***compulsory elective*** part of the programme is comprised of three courses (22.5 hec) where the student can select from nine different courses.

- *Model Predictive Control (SSY280)*
- *Modelling and Control of Mechatronic Systems (SSY156)*
- *Optimization[1] (MVE165, TDA206, TMA947)*
- *Applied Signal Processing (SSY130)*
- *Constraint Programming and Applied Optimization (EEN025)*
- *Robust and Nonlinear Control (ESS076)*
- *Simulation of Production Systems(MPR271)*
- *Sensor Fusion and Nonlinear Filtering (SSY320)*
- *System Identification (SSY230)*

In addition to fully compulsory and compulsory elective courses the programme provides multiple course packages, see Appendix 2, that can be used to specialize towards a certain application or to further focus on general methods. Not all course packages are suitable for all students, e.g. the course package in process control contains courses that require the student to have a background in chemical engineering or similar.

- Algorithms and Artificial Intelligence
- Autonomous Systems
- Control and Signal Processing
- Electric and Hybrid Powertrains
- Embedded Systems
- Industry 4.0
- Machine Learning

[1] This can be one of Linear and integer optimisation with applications, Discrete optimization or Nonlinear optimisation.

- Mathematical Systems Theory
- Power Systems
- Process Control

PROFESSIONAL SKILLS

An aim of the master programme is to prepare the student for a professional career where non-technical skills are also practiced.

The subjects covered in the programme are key technologies in order to decrease energy utilisation and the use of natural resources in, for example, traditional combustion engines; hybrid electrical/combustion engines; wind turbines; nuclear power plants; and industrial robots. In order to be able to create the new innovative products that will contribute to a sustainable future the technologies covered in the programme are often vital. Each individual course has a responsibility to exemplify how the technology in that specific course can be used for innovations and to support a sustainable future.

The compulsory course **Design project in systems, control and mechatronics** has a special responsibility for teaching and practicing the use of a structured project methodology. Searching of scientific information and assessing their relevance is practiced in several of the compulsory/compulsory elective courses, but the project course has a special responsibility to teach how to properly cite relevant scientific work and follow ethical guidelines. The students should be able to discuss how the project contributes to a sustainable future.

CAREER OPPORTUNITIES

The programme leads to a wide range of career opportunities with emphasis on operation, design, development, and research of complex technical systems within almost any branch of industry, in fact, the generality of many of the methods learnt gives great opportunities for choosing among many different application domains. The acquired skills are needed with manufacturing companies, suppliers, consulting firms, and utilities. Job roles could range from applied research to product and system development and operation, but may also extend to sales support and product planning. In addition, other career opportunities may be found as academic researchers, technical advisors, project leaders and teachers at different levels.

Appendix 1: Learning outcomes

The master's programme in Systems, Control & Mechatronics shall provide the student with ***enhanced skills for analysis and synthesis*** of complex embedded (computer controlled) products and systems. The main ***learning outcomes*** are:

- Based on a systems oriented framework, the student will be able to
  - ***discuss*** possibilities and limitations of automation and control, to ***reflect*** on its impact on humans and on society as a whole, and to ***demonstrate awareness*** of the responsibilities of the engineer in this context;
  - ***understand*** and ***present*** how control and automation can contribute to sustainable and environmentally friendly system solutions, and to ***reflect*** on the role of human interaction with these systems;
  - ***understand*** and ***explain*** how sensing and actuation (measurement and control) can be used to improve the characteristics of a technical system, and to ***analyze***, in a specific case, what is limiting the system performance;
  - ***integrate*** knowledge and information of different type and detail, and to ***handle*** complexity at the systems level by abstraction, modularization, hierarchy, and other systems engineering techniques.
- The programme will provide the student with ample opportunities to extend the systems engineering skills, so that the student will be able to
  - ***use*** methods and tools to develop ***mathematical models*** of (discrete and continuous) dynamical systems, and to be able to critically ***assess*** such models;
  - ***use*** selected model based methods for ***analysis and design*** of (continuous and/or discrete) control systems, and to be able to ***use*** computer tools for this purpose;
  - ***describe*** the architecture of a computer controlled system, from sensors to actuators, and to be able to ***specify***, ***design***, and ***implement*** such a system on a small scale;
  - ***understand*** and ***explain*** aspects of testing, verification, and error handling as parts of commissioning and operating control systems, and ***use*** computer tools for managing these aspects.
- The programme offers several course packages that will allow the students to be able to ***apply a systems perspective***, using mathematical models and methods for analysis and/or synthesis, to ***new or unfamiliar areas*** or environments related to the respective area of the course package.
- The practical training offered by the programme will enable the students to
  - ***describe*** how sensing, control and actuation is applied in selected applications;

- ***demonstrate*** ability to communicate their conclusions, and the knowledge and rationale underpinning these, to specialists and non-specialists audiences clearly and unambiguously, and in national as well as international contexts;
- ***understand*** what is expected in the professional role in terms of attitude, ethics, integrity and responsibility;
- ***apply*** a systematic work model going from specifications to implementation using a structured project methodology and having ***experienced*** such problem solving in a team;
- ***discuss*** the innovation system and intellectual property rights.
- seek and ***acquire information***, and to conduct ***independent studies*** in order to advance the personal knowledge within the area.

Appendix 2: Programme plan and course packages

Courses in a bold font are compulsory, courses in italics are compulsory elective.

The courses in the course packages shown are suggestions only, some courses might have specific prerequisites that you might or might not fulfil. With courses that are compulsory or compulsory elective we do our best to make sure that they do not interfere (e.g. lectures that are scheduled at the same time.) with each other. However, other courses might interfere with each other, please check which block the courses are scheduled in before choosing courses. Remember to always make sure that you will follow at least three of the compulsory elective courses.

	Q1 / Q5	Q2 / Q6	Q3 / Q7	Q4 / Q8
Compulsory, 1st year	**Modelling and Simulation**	**Linear Control System Design**		**Model-based Development of Cyber-Physical Systems**
	Discrete Event Systems			
Compulsory, 2nd year		**Design Project in Systems, Control and Mechatronics (1.5 hec in Q5, 6 hec in Q6)**	**Master Thesis Project, 30 hec**	
Compulsory Elective	*Robust and Nonlinear Control*	*Applied Signal processing*	*Modelling and Control of Mechatronic Systems*	*Sensor Fusion and Nonlinear Filtering*
	Constraint Programming and Applied Optimization	*Simulation of Production Systems*	*Model Predictive Control*	*System Identification*
	Nonlinear Optimisation		*Discrete Optimization*	*Linear and Integer Optimization with Applications*

Elective Courses (MPSYS owned)	Deep Machine Learning	Computer Vision		
		Advanced Topics in Control		
Voluntary courses	Preparatory Course in Matlab (3 hec)			
Soft Skills	Entrepreneurship and Project Management			

Algorithms and Artificial Intelligence	Deep Machine Learning	*Applied Signal Processing*	*Model Predictive Control*	Algorithms (also available in Q1)
	Formal Methods in Software Development	Functional Programming	Introduction to Artificial Intelligence	*Sensor Fusion and Nonlinear Filtering*
		Computer Vision	Image Analysis	*System Identification*
Autonomous Systems	Deep Machine Learning	*Applied Signal Processing*	*Model Predictive Control*	Autonomous Robots
	Stochastic Optimization Algorithms	Computer Vision	Intelligent Agents	*Sensor Fusion and Nonlinear Filtering*
	Algorithms (also available in Q4)	Advanced Topics in Control	Image Analysis	*System Identification*
Control and Signal Processing	*Robust and Nonlinear Control*	*Applied Signal Processing*	*Modelling and Control of Mechatronic Systems*	*Sensor Fusion and Nonlinear Filtering*
	Deep Machine Learning	Advanced Topics in Control	*Model Predictive Control*	*System Identification*
	Random Signals Analysis		Image Analysis	*Linear and Integer Optimization with Applications*
	Nonlinear Optimisation			

Electric and Hybrid Powertrains	Chalmers Formula Student (special application procedure)			
	Robust and Nonlinear Control	*Applied Signal Processing*	Electric and Hybrid Vehicle Propulsion	*Sensor Fusion and Nonlinear Filtering*
	Electric drives I	Li-Ion Battery Systems for Vehicles and Energy Storage Applications	*Modelling and Control of Mechatronic Systems*	*System Identification*
		Power Electronic Converters	Electric drives 2 (Formally electric drives I is a prerequisite but with some extra effort it is possible to follow the course without electric drives I)	
		Vehicle Dynamics	*Model Predictive Control*	
		Electromagnetism		
Embedded Systems	Introduction to Electronic System Design	*Applied Signal Processing*	*Modelling and Control of Mechatronic Systems*	*Sensor Fusion and Nonlinear Filtering*
	Constraint Programming and Applied Optimization	Methods for Electronic System Design and Verification	Communication Systems	Autonomous Robots
	Formal Methods in Software Development	Computer Vision		Implementation of Digital Signal Processing Systems
	Introduction to Communication Engineering			

Industry 4.0	*Constraint Programming and Applied Optimization*	*Simulation of Production Systems*	*Modelling and Control of Mechatronic Systems*	Robotics and Manufacturing Automation
	Deep Machine Learning	Design and Scheduling of Automated Production Systems	Communication Systems	*Sensor Fusion and Nonlinear Filtering*
	Formal Methods in Software Development	Computer Vision	Image Analysis	
Machine Learning	Deep Machine Learning	*Applied Signal Processing*	*Modelling and Control of Mechatronic Systems*	*System Identification*
	Stochastic Optimization Algorithms	Computer Vision	*Model Predictive Control*	*Sensor Fusion and Nonlinear Filtering*
	Algorithms (also available in Q4)		Image Analysis	Algorithms for Machine Learning and Inference
	Nonlinear Optimization			
Mathematical Systems Theory	*Robust and Nonlinear Control*	*Applied Signal Processing*	*Model Predictive Control*	*Sensor Fusion and Nonlinear Filtering*
	Functional Analysis	Advanced Topics in Control	Partial Differential Equations, First Course	*Linear and Integer Optimization with Applications*
	Random Signals Analysis		Statistical Inference	Ordinary Differential Equations and Mathematical Modelling

	Nonlinear Optimisation			

Power Systems	Power System Analysis	*Applied Signal Processing*	*Modelling and Control of Mechatronic Systems*	*Linear and Integer Optimization with Applications*
		Power Electronic Solutions for Power Systems	*Model Predictive Control*	*Sensor Fusion and Nonlinear Filtering*
		Power Electronic Converters		
Process Control	*Robust and Nonlinear Control*	Industrial Energy Systems	Advanced Chemical Engineering and Process Analytical Technology	Advanced Separation Technology
	Advanced Chemical Reaction Engineering	*Applied Signal Processing*	*Model Predictive Control*	*Linear and Integer Optimization with Applications*
	Cellulose Technology			

Double Degree programs with University of Stuttgart

Double Degree: Systems, control and mechatronics at Chalmers and Technische Kybernetik at University of Stuttgart. More information at: http://www.techkyb.de/

	Q1 / Q5	Q2 / Q6	Q3 / Q7	Q4 / Q8
Compulsory 1st year	**Modelling and Simulation**	**Linear Control System Design**	*Elective course from listed course packages*. (Model Predictive Control is recommended)*	**Model-based Development of Cyber-Physical Systems**
	Discrete Event Systems	*Elective course from course packages*.* (Applied Signal Processing is recommended)	*Elective course from course packages*. (Modelling and Control of Mechtronic systems is recommended)*	*Elective course from course packages*. (Sensor Fusion and Nonlinear Filtering is recommended)*
2nd year	Courses/internship/thesis in Stuttgart			

Note: Students with double-degree in Engineering Cybernetics need to have at least two math courses at the master level as part of their curriculum. Both courses can be completed during the first year at Chalmers, or one can be postponed to the fall semester in Stuttgart where a course in Convex optimization is offered. Math courses are shown using a green font. *At least three out of the four elective courses have to be semi-compulsory.

Double Degree: Systems, control and mechatronics at Chalmers and Mechatronik at University of Stuttgart. More information at: http://www.mechatronik.uni-stuttgart.de/

	Q1 / Q5	Q2 / Q6	Q3 / Q7	Q4 / Q8
Compulsory 1st year	**Modelling and Simulation**	**Linear Control System Design**	*Modelling and Control of Mechatronic Systems*	**Model-based Development of Cyber-Physical Systems**
	Discrete Event Systems	*Applied Signal Processing or Simulation of Production Systems*	*Elective course from course packages*	*Sensor Fusion and Nonlinear Filtering*
2nd year	Courses/internship/thesis in Stuttgart			

Double Degree: Systems, control and mechatronics at Chalmers and Technische Kybernetik at University of Stuttgart. More information at: http://www.techkyb.de/