Curriculum for the Master’s Programme in Control and Automation

Aalborg University
September 2017

Campus: Aalborg
Preface:
Pursuant to Act 261 of March 18, 2015 on Universities (the University Act) with subsequent changes, the following curriculum for the Master's programme in Control and Automation is stipulated. The programme also follows the Joint Programme Regulations and the Examination Policies and Procedures for The Technical Faculty of IT and Design.
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Chapter 1: Legal Basis of the Curriculum, etc.

1.1 Basis in ministerial orders
The Master’s programme in Control and Automation is organised in accordance with the Ministry of Higher Education and Science’s Order no. 1061 of June 30, 2016 on Bachelor’s and Master’s Programmes at Universities (the Ministerial Order of the Study Programmes) and Ministerial Order no. 1062 of June 30, 2016 on University Examinations (the Examination Order). Further reference is made to Ministerial Order no. 258 of March 18, 2015 (the Admission Order) and Ministerial Order no. 114 of February 3, 2015 (the Grading Scale Order) with subsequent changes.

1.2 Faculty affiliation
The Master’s programme falls under the Technical Faculty of IT and Design, Aalborg University.

1.3 Board of Studies affiliation
The Master’s programme falls under the Board of Studies for Electronics and IT.

1.4 Body of external examiners
The programme is affiliated with the body of external examiners for engineering educations: electro (In Danish: censorkorps for Ingeniøruddannelsernes landssækkende censorkorps; elektro).

Chapter 2: Admission, Degree Designation, Programme Duration and Competence Profile

2.1 Admission
Applicants with a legal claim to admission (retnskrav):
Applicants with one of the following degrees are entitled to admission:

- Bachelor of Science in Electronics and IT, Aalborg University
- Bachelor of Science in Computer Engineering, Aalborg University

Applicants without legal claim to admission:
Students with another Bachelor's degree, upon application to the Board of Studies, will be admitted after a specific academic assessment if the applicant is deemed to have comparable educational prerequisites. The University can stipulate requirements concerning conducting additional exams prior to the start of study.

2.2 Degree designation in Danish and English
The Master’s programme entitles the graduate to the designation civilingeniør, cand.polyt. (candidatus/candidata polytechnices) i regulering og automation. The English designation is: Master of Science (MSc) in Engineering (Control and Automation).

2.3 The programme’s specification in ECTS credits
The Master’s programme is a 2-year, research-based, full-time study programme. The programme is set to 120 ECTS credits.

2.4 Competence profile on the diploma
The following competence profile will appear on the diploma:

A graduate of the Master’s programme has competencies acquired through an educational programme that has taken place in a research environment.

The graduate of the Master’s programme can perform highly qualified functions on the labor market on the basis of the educational programme. Moreover, the graduate has prerequisites for research (a Ph.D. programme). Compared to the Bachelor’s
degree, the graduate of the Master’s programme has developed her/his academic knowledge and independence, so that the graduate can independently apply scientific theory and method in both an academic and occupational/professional context.

2.5 Competence profile of the programme:

The graduate of the Master’s programme:

Knowledge
- Has scientifically based knowledge about modeling and control methods for complex control systems
- Has an understanding of the concept of modern control
- Must understand analytical, numerical and experimental methods for analysis and design of complex control systems
- Has knowledge about distributed systems and data networks for control purposes
- Has knowledge in one or more subject areas that is based on the highest international research within the fields of control engineering

Skills
- Can analyze and apply modern control methods for multi input/multi output systems.
- Demonstrate insight in relevant theories, methods and techniques used for distribution, storage and processing of data in a distributed system
- Can apply data networks for control purposes
- Demonstrate insight in real-time, performance, safety and robustness aspects
- Can apply modeling methods for dynamic mechanical and thermal systems
- Can analyze specific control methods used for control of mechanical or thermal systems.
- Can select and apply advanced methods of control and estimation when applied to complex systems.
- Demonstrate comprehension of optimal and robust control theory
- Can apply appropriate methods of analysis for investigating control problems in industrial plants.
- Can communicate research-based knowledge and discuss professional and scientific problems with peers as well as non-specialists, using the correct terminology.

Competencies
- Can select and apply appropriate methods for solving a given problem within control and automation and evaluate the results regarding their accuracy and validity
- Can identify scientific problems within control and automation and select and apply proper scientific theories, methods and tools for their solution
- Can develop and advance new analyses and solutions within control and automation
- Can manage work-related situations that are complex and
unpredictable, and which require new solutions

- Can initiate and implement discipline-specific as well as interdisciplinary cooperation and assume professional responsibility
- Can take responsibility for own professional development and specialization.
- Work according to a scientific method and present results in the form of a scientific article and at a seminar/scientific conference
- Formulate and explain scientific hypotheses and results achieved through scientific work
- Analyze results and draw conclusions on a scientific basis

**Chapter 3: Content and Organization of the Programme**

The programme is structured in modules and organised as a problem-based study. A module is a programme element or a group of programme elements, which aims to give students a set of professional skills within a fixed time frame specified in ECTS credits, and concluding with one or more examinations within specific exam periods. Examinations are defined in the curriculum.

The programme is based on a combination of academic, problem-oriented and interdisciplinary approaches and organised based on the following work and evaluation methods that combine skills and reflection:

- lectures
- classroom instruction
- project work
- workshops
- exercises (individually and in groups)
- teacher feedback
- reflection
- portfolio work
Overview of the programme:

All modules are assessed through individual grading according to the 7-point scale or Pass/Fail. All modules are assessed by external examination (external grading) or internal examination (internal grading or by assessment by the supervisor only).

<table>
<thead>
<tr>
<th>Semester</th>
<th>Module</th>
<th>ECTS</th>
<th>Assessment</th>
<th>Exam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>Networked Control Systems *)</td>
<td>15</td>
<td>7-point scale</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Stochastic Processes</td>
<td>5</td>
<td>7-point scale</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Distributed Real Time Systems</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Multivariable Control</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td>2nd</td>
<td>Multivariable Control Systems</td>
<td>15</td>
<td>7-point scale</td>
<td>External</td>
</tr>
<tr>
<td></td>
<td>Modeling of Mechanical and Thermal Systems</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Optimality and Robustness</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Robot Vision (Elective)</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Fault Detection, Isolation and Modelling (Elective)</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td>3rd</td>
<td>Control of Complex Systems</td>
<td>20</td>
<td>7-point scale</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Systems of Systems/Complex Systems (Elective)</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Machine Learning (Elective)</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Non-linear Control (Elective)</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td>4th</td>
<td>Master’s Thesis</td>
<td>30,  possibly 60</td>
<td>7-point scale</td>
<td>External</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*) A compulsory course in Problem Based Learning (PBL) is offered as an integrated part of the project module to non-AAU bachelors. If non-AAU students get credit transfer for the 1st Semester project module, then it has to be ensured that they get the PBL competences in other ways.

On 3rd Semester the student must choose two of the three elective courses
Networked Control Systems (15 ECTS)
Netværksbaserede kontrolsystemer

Prerequisites:
Knowledge and skills in Control System Analysis, Design and Implementation including Classic and Modern Model Based Controllers. Basic skills in Dynamic Modeling and in Solving Problems Involving Information Technology

Competencies in problem and project based learning.

Objective:
Students who complete the module: have implemented a controller for a system with multiple inputs and outputs involving the use of a network. One aim is that the student should be able to design and analyze commonly used networks and protocols with focus on their real time properties. A second aim is that the student is able to design and implement classical solutions for multivariable control along with modern state space solutions including state feedback and feedback from observed states. Special attention is given to the implication of timing and timing variations in the network on the control behavior

Students who complete the module:

Knowledge
- Must have knowledge about common control structures
- Must have knowledge about common communication standards, protocols and network topologies
- Must be able to understand network system models

Skills
- Must be able to implement a control system using a selected network standard and analyze timing properties relevant for the control system behavior
- Must be able to design and implement classic and modern controllers for a multivariable system and analyze closed loop properties like pole placement, disturbance rejection and reference following.
- Can explain the process of and criteria for peer reviewed scientific communications
- Can write a paper for a scientific conference/journal
- Can prepare and give an oral and poster presentation for a scientific conference

Competencies
- Must have competencies in analysis and design of control of systems in state space formulation including state feedback and observer design.
- Must have competencies in design and implementation of distributed real time systems and real time requirements for control systems.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral examination
The examination is based on questions that take their starting points in the written documentation for the project module.
For further information concerning the examination procedure, refer to the Joint Programme Regulations.
**Evaluation criteria:**
As stated in the Joint Programme Regulations, it is a precondition for students, with a non-AAU bachelor's degree that they have passed the course in Problem Based Learning (PBL) at Aalborg University prior to the project examination.
Problem Based Learning (PBL) at Aalborg University
Problembaseret læring på Aalborg Universitet

Prerequisites:
None, but the course is compulsory for non-AAU bachelors

Learning outcomes:
After completion of the course the student should

Knowledge
- know how to describe in own words some of the fundamental principles of Problem Based Learning (PBL) as implemented in the Aalborg PBL model at the Faculty of Engineering and Science.
- Know how to identify similarities and differences between the Aalborg PBL study environment and previous study environments, incl. strengths and weakness in both environments.

Skills
- be able to structure project management activities based on a well-formulated problem statement
- be able to assess project documentation based on scientific codes of conduct

Competences
- be able to plan for effective collaborative learning in an intercultural environment and manage group conflicts
- be able to reflect on, plan and manage a study project in a PBL learning environment

Content:
Lectures, discussions and group work.

Assessment:
Internal assessment during the course/class participation according to the rules in the Examination Policies and Procedures, Addendum to the Joint Programme Regulations of the Technical Faculty of IT and Design, Aalborg University. In this case the assessment is primarily based on the oral performance during the course. This means that the student has to be active during the course time and participate in discussions. The course is an integrated part of the project and a precondition for participation in the project examination for non-AAU bachelors. Consequently, no diploma will be issued for the course nor will it appear on the academic transcripts.

Grading:
Passed/Failed

Assessment criteria:
As stated in the Joint Programme Regulations
Stochastic Processes (5 ECTS)
Stokastiske processer

Prerequisites:
Solid knowledge in Probability, Statistics, Linear Algebra, Fourier Theory, and Programming

Objective:
Students who complete the module must:

Knowledge
- Have knowledge about the theoretical framework in which stochastic processes are defined.
- Be able to understand the properties of the stochastic processes introduced in the course, such as wide-sense stationary (WSS) processes, Auto Regressive Moving Average (ARMA) processes, Markov models, and Poisson point processes.
- Be able to understand how WSS processes are transformed by linear time-invariant systems.
- Be able to understand the theoretical context around the introduced estimation and detection methods ((non-parametric and parametric) spectral estimation, Linear Minimum Mean Square Error (LMMSE) estimation, Wiener filter, Kalman filter, detection of signals, ARMA estimation, etc.)

Skills
- Be able to apply the stochastic processes taught in the course to model real random mechanisms occurring in engineering problems.
- Be able to simulate stochastic processes using a standard programming language.
- Be able to apply the taught estimation and detection methods to solve engineering problems dealing with random mechanisms.
- Be able to evaluate the performances of the introduced estimation and detection methods.

Competencies
- Have the appropriate “engineering” intuition of the basic concepts and results related to stochastic processes that allow – for a particular engineering problem involving randomness – to design an appropriate model, derive solutions, assess the performance of these solutions, and possibly modify the model, and all subsequent analysis steps, if necessary.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations
Distributed Real Time Systems (5 ECTS)

Prerequisites:
Basics in Basic Network Communication and Protocols as e.g. obtained in courses Communication in Electronic Systems (EIT 5th Semester) or Network Technologies and Distributed Systems (ITC 5th Semester)

Objective:
Students who complete the module:

Knowledge
The students must have insight in:
- fieldbus technologies and concepts of communication
- global state protocols
- replication of systems for redundancy concerns
- application domains and their requirements, relevant Quality of Service parameters
- queuing theory, basic models
- synchronization issues
- reliability modeling, including safety, scalability, maintainability issues
- modeling tools, such as Deterministic Network Calculus
- network simulation tools (examples include ns-2/ns-3, OMNET)

Skills
The students must have understanding of …
- Service models for field bus and their limitation
- utilizing consistency between automates in a distributed system
- describing a loose coupled system with basic traffic pattern modeling
- home automation and similar domain areas in perspective of communication and safety
- quality of service
- protocol design

Competencies
The students must be able to
- identify requirements and select an appropriate communication architecture
- analyze and design complex networked systems with hard requirements such as providing real time guarantees
- model system behavior using analytical or simulation tools

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations
**Multivariable Control (5 ECTS)**

*Flervariable reguleringssystemer*

**Prerequisites:**
Skills in Analyses and Design of Classical Control Systems

**Objective:**
To expand qualifications in classic control and to introduce modern control methods based on state space description.

Students who complete the module:

**Knowledge**

**Skills**
- Control of large scale systems
- Optimal control
- Anti integrator windup
- Reduced order observers
- Control of unit operations: e.g. boiler control, evaporation control, distillation control, energy transport control, reactor control, heat exchanger control.
- Control of large scale systems e.g. sugar production, power production, cement production

**Competencies**
- Root locus design
- Digital control methods
  - Design by emulation
  - Discrete design
- Advanced classic MIMO control system design
  - Top-down versus bottom-up control design
  - Classic linear control elements: feedback, feed forward, cascade, decoupling
  - Special control elements: ratio control, split range, mid ranging, large loop control, repetitive control
  - Non-linear elements: minimum-maximum, selectors, gain scheduling, limiters, variable structure
  - Basic control elements: level control, temperature control, enthalpy control, pressure control, flow control.
- Time delays
- State space control
  - Poles and zeros of state space models
  - State space transformations
  - Controllability
  - State feedback design
  - Observability
  - Observer gain design
  - Observer based control
  - Separations theorem
Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations
2\textsuperscript{nd} Semester

Multivariable control systems (15 ECTS)

\textit{Flervariable reguleringssystemer}

\textbf{Prerequisites:}
1\textsuperscript{st} Semester

\textbf{Objective:}
Students who complete the module: must be able to analyze modern control methods for multi input/multi output systems and to apply modeling methods and control synthesis for mechanical or energy conversion systems.

Students who complete the module:

\textbf{Knowledge}
- Stability and performance limitations in robust control
- Additive and multiplicative model uncertainty
- Robust stability
- Robust performance
- Small gain theorem
- Dynamic programming
- Riccati equation
- Elimination of steady state errors in optimal control
- Use of observer in LQG control
- Stability properties of optimal controller
- Stability properties of finite horizon control
- Solving predictive control with constraints using quadratic programming
- Dealing with uncertain and nonlinear systems in model predictive control.
- Mass- and energy balances
- Fundamental laws of thermodynamics
- Models with lumped and distributed parameters
- Model structures for system identification: AR, MA, ARMA, ARMAX, Box-Jenkins
- System identification methods: Moment method, Least squares method, Prediction error method, Maximum likelihood method, Recursive and adaptive parameter estimation
- Lagrange and Hamiltonian mechanics
- Rotation parameters, rotation matrices, quaternion
- Model representations (differential equations, state space, transfer function, differential-algebraic equations, descriptor form)

\textbf{Skills}
- Formulation of optimal control problems with references and disturbances
- Soft real time implementation
- Formulation of the standard robustness problem
- Theory and solution to the standard robust problem
- Formulation of control problems using models of constraints, disturbances and references
combined with a performance function (Model Predictive Control)

- Software tools for solving constrained optimization problems
- Should be able to formulate models of a basic energy conversion systems and mechanical systems.
- Should be able to apply system identification methods

**Competencies**

**Type of instruction:**
As described in the introduction to Chapter 3.

**Exam format:**
Individual oral examination

The examination is based on questions that take their starting points in the written documentation for the project module.

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

**Evaluation criteria:**
As stated in the Joint Programme Regulations
Modeling of Mechanical and Thermal Systems (5 ECTS)

Modellering af mekaniske og termiske systemer

Prerequisites:
Knowledge and skills in Control System Analysis, Design and Implementation including Classic and Modern Model Based Controllers. Basic skills in Dynamic Modeling and in solving problems involving Information Technology

Objective:
Students who complete the module:

Knowledge
- Mass- and energy balances
- Preservation of momentum
- Definition of control volumes, Reynolds theorem
- Empirical relations for heat transfer friction
- Properties for liquids and gasses
- Fundamental laws of thermodynamics
- Models with lumped parameters
- Models with distributed parameters
- Model structures for system identification: AR, MA, ARMA, ARMAX, Box-Jenkins
- System identification methods: Moment method, Least squares method, Prediction error method, Maximum likelihood method, Recursive and adaptive parameter estimation
- Lagrange and Hamiltonian mechanics
- Coordinate systems and coordinate transformation for mechanical systems.
- Rotation parameters, rotation matrices, quaternions
- Kinematics
- Satellite and Robot dynamics
- Model representations (differential equations, state space, transfer function, differential-algebraic equations, descriptor form)
- Model reduction
- Linearization
- Model properties (controllability, observability, stability)

Skills
- Should be able to formulate models of a basic energy conversion systems and mechanical systems.
- Should be able to apply system identification methods
- Should be able to adapt the model to a suitable representation.

Competencies
- Capable of modeling a system with sufficient information level, suitable for solving a given control problem

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination
For further information concerning the examination procedure, refer to the Joint Programme Regulations.

**Evaluation criteria:**
As stated in the Joint Programme Regulations
Optimality and Robustness (5 ECTS)
Optimal- og robust regulering

Prerequisites:
Knowledge and skills in Control System Analysis, Design and Implementation including State Space Controllers

Objective:
The aim of this module is to obtain qualifications in formulation and solution of control problems where the objective can be formulated as an optimization problem in which the trajectories of inputs, state variables and outputs are included in an objective function and can be constrained. The formulation will include a model which describes the dynamic behavior of the physical plant with given control inputs and disturbances. Models describing disturbances and references can be included to describe predictive problems. A further aim is to provide methods to analyze robustness of closed loop stability and performance when discrepancy between the physical plant and the model is bounded by specified uncertainty bounds and to study dimensioning methods, which aim to ensure robustness of stability and performance given specified uncertainty bounds.

Students who complete the module:

Knowledge
- Must have an understanding of basic concepts within optimal control, such as linear models, quadratic performance, dynamic programming, Riccati equations etc.
- Must have an understanding of the use of observers to estimate states in a linear dynamical system
- Must have insight into the stability properties of optimal controllers
- Must have insight into the stability properties of finite horizon control, and how to ensure stability
- Must have knowledge about performance specifications that are not quadratic
- Must have knowledge of additive and multiplicative model uncertainty
- Must have insight into the small gain theorem and its applications in robust control
- Must have insight into robust stability and robust performance

Skills
- Must be able to formulate linear control problems using models of disturbances and references combined with a quadratic performance function and solve them using appropriate software tools, e.g. Matlab
- Must be able to introduce integral states in control laws to eliminate steady state errors
- Must be able to design observers while taking closed-loop stability into account
- Must be able to utilize quadratic programming to solve predictive control problems with constraints.
- Must be able to use software tools such as Matlab to solve constrained optimization problems
- Must be able to formulate the standard robustness problem as a two-input-two-output problem and solve it using appropriate methods
- Must be able to assess the limitations model uncertainty sets impose on the achievable performance for systems described by linear models
- Must be able to use singular value plots and the H infinity norm of appropriate transfer function to assess robustness
- Must be able to perform H infinity norm optimization as a method to tune controllers.
Competencies
- Must be able to formulate and solve optimal control problems with references and disturbances
- Must understand the implications of disturbances and uncertainties in the context of linear dynamical systems, and be able to address these via robust control design

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination.

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations
Robot Vision (Elective) (5 ECTS)

Robot Vision

Prerequisites:
Basic knowledge in Linear Algebra and Statistics

Objective:
Students who complete the module will gain knowledge, skills and competences as follows:

Knowledge
- Must have gained an understanding of fundamental concepts related to robotics.
- Must have an understanding of how vision and other sensors can be integrated with a robot
- Must have an understanding of relevant technologies enabling the design of intelligent machines (artificial intelligence).
- Must have an understanding of highly flexible and integrated automation technologies.
- Must have an understanding of the business potential of intelligent manufacturing.

Skills
- Must be able to use various technologies to provide manufacturing systems with intelligent capabilities (reasoning, knowledge, planning, learning, communication, perception and the ability to move and manipulate objects).
- Must be able to model the direct and inverse kinematics of a robot.
- Must be able to design simple trajectory planners, including Cartesian and joint interpolators
- Must be able to program an industrial robot to carry out various tasks
- Must be able to integrate vision with an industrial robot.
- Must be able to integrate and implement intelligent machines into a small and limited manufacturing system.

Competencies
- Must have the foundation to participate in projects aiming at designing intelligent manufacturing systems which more or less autonomously can adapt to variations in its environment and, over time, improve its performance.

Type of instruction:
The form(s) of teaching will be determined and described in connection with the planning of the Semester. The description will account for the form(s) of teaching and may be accompanied by an elaboration of the roles of the participants. The course/project theme is performed in either English or Danish dependent of the language skills of the participants.

Exam format:
Individual oral exam on the basis of a small report and a practical demonstration. An internal censor participates in the exam.

Evaluation criteria:
As stated in the Joint Programme Regulations.
Fault Detection, Isolation and Modeling (Elective) (5 ECTS)

Fejldetektion, -isolation og -modellering

Prerequisites:
Basic Probability Theory, Dynamical Systems formulated in State Space and Frequency, Stochastic Processes

Objective:
Every real life system will at some point or another experience faults. Students who complete this course will be able to, in a systematic manner, to analyze dynamic systems as well as distributed, network coupled systems. For each of the two system types the student will be able to:

- List the different considered faults, how they propagate through the system and assess their severity and occurrence likelihood.
- Develop methods for estimating if a given fault is present or not.
- Develop fault tolerant strategies for ensuring the continuation of the system in the presence of faults.

Students who complete the module:

Knowledge
- The taxonomy of fault tolerant systems
- Simulation tools for testing and verification

Skills
- In analyzing a system for possible faults and modeling these
  - Failure Mode and Effect Analysis
  - Structural analysis
  - Faults in TCP/IP based Networks
- In evaluating the severity of different faults and prioritizing
  - By means of simulations
  - Stochastic models for components and their availability
- In designing detectors for selected faults
  - Structural analysis
    - Analytical Redundancy Relations
  - Passive fault detection
    - Unknown input observers
    - Parameter estimators
    - Parity space filters
  - Active fault detection
    - Design of perturbation signals
    - Neighbor discovery
    - Round-trip time
    - Heartbeats
    - Acknowledged transmissions
  - Decision ruling
    - Threshold based
- Stochastic based
- In designing strategies for handling faults
  - Passive fault tolerance
    - Robust controllers
    - Reliable message broadcasting
    - Multipath routing
  - Active fault tolerance
    - Control strategy change
    - Redundant systems with backup components

**Competencies**
- In designing fault tolerance strategies for a given system

**Type of instruction:**
As described in the introduction to Chapter 3.

**Exam format:**
Individual oral or written examination

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

**Evaluation criteria:**
As stated in the Joint Programme Regulations
3rd Semester

Control of complex systems (20 ECTS)
Regulering af komplekse systemer

Prerequisites:
2nd Semester

Objective:
Students who complete the module:

Knowledge
- Must have knowledge about modeling of electromechanical and thermal systems.
- Must be able to understand methods for control of complex systems

Skills
- Must be able to analyze methods of state observation, parameter estimation and sensor information fusion in systems
- Must be able apply methods of supervisory control, fault tolerant control or fault detection

Competencies
- Must be able to design and implement a control system for a complex system.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral examination
The examination is based on questions that take their starting points in the written documentation for the project module.
For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations
Systems of Systems/Complex Systems (Elective) (5 ECTS)

Komplekse systemer

Prerequisites:
Knowledge from the areas of Systems and Control Theory, Network Theory, Distributed Systems and Embedded Systems

Objective:
The students will be introduced to methodologies for design of a system of systems in terms of designing the properties of the individual systems as well as their interconnecting behavior, establishing the system of systems. A systematic approach to the design of network architectures and local behavior rules, which together constitute systems of systems that are optimal with respect to objectives formulated at a macroscopic level, will be presented.

Students who complete the module:

Knowledge
- The formalized concept of systems of systems
- A systematic approach to the design of network architectures and local behavior rules, which together constitute systems of systems that are optimal with respect to objectives formulated at a macroscopic level.

Skills
- To combine the areas of systems and control theory, network theory, distributed systems and embedded systems into design principles for systems of systems
- Design of the properties of the individual systems, as well as their interconnecting behavior, establishing the system of systems

Competencies

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination.

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations
Machine Learning (Elective) (5 ECTS)

Prerequisites:
Basic knowledge in Probability Theory, Statistics, and Linear Algebra

Objective:
The course gives a comprehensive introduction to machine learning, which is a field concerned with learning from examples and has roots in computer science, statistics and pattern recognition. The objective is realized by presenting methods and tools proven valuable and by addressing specific application problems.

Students who complete the module:

Knowledge
- Must have knowledge about supervised learning methods including K-nearest neighbors, decision trees, linear discriminant analysis, support vector machines, and neural networks.
- Must have knowledge about unsupervised learning methods including K-means, Gaussian mixture model, hidden Markov model, EM algorithm, and principal component analysis.
- Must have knowledge about probabilistic graphical models, variational Bayesian methods, belief propagation, and mean-field approximation.
- Must have knowledge about Bayesian decision theory, bias and variance trade-off, and cross-validation.
- Must be able to understand reinforcement learning.

Skills
- Must be able to apply the taught methods to solve concrete engineering problems.
- Must be able to evaluate and compare the methods within a specific application problem.

Competencies
- Must have competencies in analyzing a given problem and identifying appropriate machine learning methods to the problem.
- Must have competencies in understanding the strengths and weaknesses of the methods.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination.

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations
Non-linear Control (Elective) (5 ECTS)
Ikke-lineære kontrolsystemer

Objective:
Students who complete the module will obtain skills within Nonlinear Control including analysis of controllability, observability, and stabilizability and stability, along with control synthesis for non-linear systems, hybrid systems covering dynamical system with both discrete and continuous components, the optimal linear estimator - the Kalman filter - as well as non-linear estimation and sensor fusion.

Students who complete the module:

Knowledge
- Lyapunov stability
- Backstepping
- Linear Kalman Filters and their limitations
- The extended Kalman filter
- The unscented Kalman filter
- Particle filtering
- Kalman filters as parameter estimators
- The influence of (coloured) sensor and model noise on the filter estimate.
- Must be able to understand...
- The invariance principle
- Feedback linearization

Skills
- Controllability
- Observability
- Online estimation techniques to a given system
- Understand and analyze systems with multiple sensors for the purpose of fusing sensor information to control-relevant information
- Stabilizability

Competencies

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination.

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations
Master's Thesis (30, possibly 60 ECTS)  
*Kandidatspeciale*

The master thesis can be conducted as a long master thesis. If choosing to do a long master thesis, it has to include experimental work and has to be approved by the study board. The amount of experimental work must reflect the allotted ECTS.

**Prerequisites:**
1st – 3rd Semester

**Objective:**
Students who complete the module:

**Knowledge**
- have knowledge, at the highest international level of research, of at least one of the core fields of the education
- have comprehension of implications of research (research ethics)

**Skills**
- are able to reflect on a scientific basis on their knowledge,
- can argue for the relevance of the chosen problem to the education including specifically account for the core of the problem and the technical connections in which it appears
- can account for possible methods to solve the problem statements of the project, describe and assess the applicability of the chosen method including account for the chosen delimitation and the way these will influence on the results of the product
- can analyze and describe the chosen problem applying relevant theories, methods and experimental data
- are able to describe the relevant theories and methods in a way that highlights the characteristics and hereby document knowledge of the applied theories, methods, possibilities and delimitations within the relevant problem area
- have the ability to analyze and assess experimental data, including the effect the assessment method has on the validity of the results.

**Competencies**
- are able to communicate scientific problems in writing and orally to specialist and non-specialist.
- are able to control situations that are complex, unpredictable and which require new solutions,
- are able to independently initiate and to perform collaboration within the discipline and interdisciplinary as well, and to take professional responsibility,
- are able to independently take responsibility for his or her own professional development and specialization.

If the project is carried out as a long master's thesis the learning objectives include those defined for the 3rd Semester of the education.

**Type of instruction:**
As described in the introduction to Chapter 3.

**Problem based project oriented project work individual or in groups of 2-3 persons**

**Exam format:**
Individual oral examination. An external censor is appointed.

The examination is based on questions that take their starting points in the written documentation for the project module.

For further information concerning the examination procedure, refer to the Joint Programme
Regulations.

**Evaluation criteria:**
As stated in the Joint Programme Regulations
Chapter 4: Entry into Force, Interim Provisions and Revision

The curriculum is approved by the Dean of The Technical Faculty of IT and Design and enters into force as of September 2017.

Students who wish to complete their studies under the previous curriculum from 2011 must conclude their education by the summer examination period 2018 at the latest, since examinations under the previous curriculum are not offered after this time.

Chapter 5: Other Provisions

5.1 Rules concerning written work, including the Master's thesis
In the assessment of all written work, regardless of the language it is written in, weight is also given to the student's spelling and formulation ability, in addition to the academic content. Orthographic and grammatical correctness as well as stylistic proficiency are taken as a basis for the evaluation of language performance. Language performance must always be included as an independent dimension of the total evaluation. However, no examination can be assessed as ‘Pass’ on the basis of good language performance alone; similarly, an examination normally cannot be assessed as ‘Fail’ on the basis of poor language performance alone.

The Board of Studies can grant exemption from this in special cases (e.g., dyslexia or a native language other than Danish).

The Master's thesis must include an English summary.\(^1\) If the project is written in English, the summary must be in Danish.\(^2\) The summary must be at least 1 page and not more than 2 pages. The summary is included in the evaluation of the project as a whole.

5.2 Rules concerning credit transfer (merit), including the possibility for choice of modules that are part of another programme at a university in Denmark or abroad
In the individual case, the Board of Studies can approve successfully completed (passed) programme elements from other Master's programmes in lieu of programme elements in this programme (credit transfer). The Board of Studies can also approve successfully completed (passed) programme elements from another Danish programme or a programme outside of Denmark at the same level in lieu of programme elements within this curriculum. Decisions on credit transfer are made by the Board of Studies based on an academic assessment. See the Joint Programme Regulations for the rules on credit transfer.

5.3 Rules for examinations
The rules for examinations are stated in the Examination Policies and Procedures published by the Technical Faculty of IT and Design on their website.

5.4 Exemption
In exceptional circumstances, the Board of Studies study can grant exemption from those parts of the curriculum that are not stipulated by law or ministerial order. Exemption regarding an examination applies to the immediate examination.

5.5 Rules and requirements for the reading of texts
It is assumed that the student can read academic texts in his or her native language as well as in English and use reference works etc. in other European languages.

\(^1\) Or another foreign language (upon approval from the Board of Studies)
\(^2\) The Board of Studies can grant exemption from this.
5.6 Additional information
The current version of the curriculum is published on the Board of Studies’ website, including more
detailed information about the programme, including exams.