GHENT UNIVERSITY

Course Specifications

Valid as from the academic year 2020-2021

Modelling and Simulation of Dynamical Systems (E005722)

Due to Covid 19, the education and evaluation methods may vary from the information displayed in the schedules and course details. Any changes will be communicated on Ufora.

Course size (nominal values; actual values may depend on programme)

Credits 6.0 Study time 180 h Contact hrs 60.0 h

Course offerings and teaching methods in academic year 2020-2021

A (semester 2)	English	Gent	seminar	15.0 h
			lecture	30.0 h
			project	15.0 h

Lecturers in academic year 2020-2021

Crevecoeur, Guillaume	TW08	lecturer-in-charge

Offered in the following programmes in 2020-2021	crdts	offering
Bridging Programme Master of Science in Electromechanical Engineering (main subject Control Engineering and Automation)	6	A
Bridging Programme Master of Science in Industrial Engineering and Operations Research	6	A
Bridging Programme Master of Science in Industrial Engineering and Operations Research	6	A
Master of Science in Electromechanical Engineering (main subject Control Engineering and Automation)	6	A
Master of Science in Electromechanical Engineering (main subject Electrical Power Engineering)	6	A
Master of Science in Electromechanical Engineering (main subject Maritime Engineering)	6	A
Master of Science in Electromechanical Engineering (main subject Mechanical Construction)	6	A
Master of Science in Electromechanical Engineering (main subject Mechanical Energy Engineering)	6	A
Master of Science in Industrial Engineering and Operations Research	6	A
Master of Science in Chemical Engineering	6	A
Master of Science in Industrial Engineering and Operations Research	6	A
Master of Science in Chemical Engineering	6	A

Teaching languages

English

Keywords

dynamic systems, modelling, simulation, dynamic behavior, optimization, optimal control.

Position of the course

This course is about the modelling and simulation of dynamical systems to analyse the behaviour and optimizing the performance of electromechanical systems. These systems become progressively more integrated with interactions of physical phenomena stemming from different engineering domains: mechanics, fluid flow, electronics, etc. Additionally, the ubiquity of data arising from advancements in sensors allows to learn from data and extract behavioural patterns. To advance upon the design of dynamical systems one can rely on apprehending and predicting their behaviour. To optimize the operational performance, model based control approaches possess the capability to find feedforward optimal control actions.
Model based system engineering provides a means to tackle the above-mentioned

challenges in the engineering of physical dynamical systems. Various computational approaches are studied that are key in system engineering. This course offers:
(1) tools to model multi-domain engineering systems. Systematic approaches are provided that formulate practical mathematical models of a physical process. To that end, physics-based models that are based on energetic formalisms, i.e. Lagrangian and Hamiltonian equations of motion, graph-based models and data-driven models are presented.
(2) tools to simulate and analyse system behaviour. The accuracy of the time-based simulations requires in depth knowledge of the algorithms to calculate the future state of systems.
(3) tools to optimally control nonlinear systems and optimize their performance. Deterministic and stochastic optimization techniques that underpin model based control are provided. Both continuous time and discrete time nonlinear optimal control approaches are presented.
Finally, hybrid system consisting of continuous time dynamics and discrete event-driven dynamics are studied with automata and Petri net formalisms.
The presented methodologies are applied on mechatronic and robotic applications such as the double pendulum, electromechanical drivetrains, car suspensions, wind turbines and robot arms.

Contents

1. Introduction and general scope: modelling of process, model types, concept of control
2. Physics based modelling: calculus of variations, Euler-Lagrange equation, Lagrangian equations of motion, Hamiltonian equations of motion
3. Graph based modelling: efforts and flows, power flows, bondgraph model, bondgraph networks
4. Data driven modelling: least-squares regression, maximum likelihood estimation, Bayesian approach, multivariate models, neural networks and machine learning, classification, model order reduction
5. Simulation of dynamical systems for system engineering: initial value problems: existence and uniqueness, Lyapunov functional, implicit and explicit time stepping, single step, multi-step, variable step; rootfinders; boundary value problems: shooting methods, parametric boundary value problem for trajectory generation
6. Optimization for model based system engineering design: problem definition, optimality conditions, gradient based methods, sequential quadratic programming, stochastic gradient descent, stochastic population based and distribution based methods
7. Model based control: continuous time and discrete time nonlinear optimal control
8. Hybrid systems: discrete state systems, languages and automata, Petri nets

Project: implementation of computational algorithms for the modelling and simulation of dynamical systems with the finality to assess the behavior of systems and optimize their performance.

Initial competences

Mathematical analysis (differential equations, linear algebra, Taylor series and convergence), physics (mechanics, electromagnetism, power and energy), basics of probability and statistics.

Final competences

1 Insight in how to model a complicated system: simplest possible accurate system model.
2 Use of compositionality, abstraction, hierarchy to develop mathematical models of systems, to be able to implement for simulation, to reduce and to validate.
3 Use of Euler-Lagrange and Hamiltonian methods.
4 To be able to implement mathematical models of continuous systems for simulation purposes using numerical integration routines.
5 Use of data driven models for regression and classification.
6 Design model based controllers for continuous time and discrete time system models.
7 Use of computer platforms for the implementation of simulation programs.
8 Develop system models for systems having asynchronous events using automata and Petri nets.

Conditions for credit contract

Access to this course unit via a credit contract is determined after successful competences assessment

Conditions for exam contract

This course unit cannot be taken via an exam contract

Teaching methods

Lecture, project, seminar

Learning materials and price

Lecture notes in English

References

- Karnopp, Marcolis and Rosenberg: System Dynamics: Modelling and simulation of mechatronic systems, Wiley, 2000
- P.P. Varaiya: Notes on Optimization, Van Nostrand Reinhold 1972
- A. van der Schaft en H. Schumacher: An introduction to Hybrid Dynamical Systems, Springer, 2000
- T. Braunl: Embedded Robotics, Springer, 2003

Course content-related study coaching

Evaluation methods

end-of-term evaluation and continuous assessment

Examination methods in case of periodic evaluation during the first examination period

Oral examination

Examination methods in case of periodic evaluation during the second examination period

Oral examination

Examination methods in case of permanent evaluation

Report

Possibilities of retake in case of permanent evaluation

examination during the second examination period is possible in modified form

Extra information on the examination methods

During examination period: oral closed-book exam, written preparation. During semester: graded project reports.

Calculation of the examination mark

Students must successfully complete the project during the semester, and pass the oral, closed book exam; score consists of 30% for oral presentation and written report on project work during the semester, and for 70% for oral exam.