information brochure 2015-2016 interuniversitary graduate school

systems and control

colofon

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The Dutch Institute of Systems and Control DISC has been established on January 1, 1995, by the Delft and Eindhoven Universities of Technology and the University of Twente. The administratively responsibility rests with the Faculty of Mechanical, Maritime and Materials Engineering of the Delft University of Technology.
DISC's graduate school is formally accredited by the Royal Dutch Academy of Sciences.

contents

disc – general introduction

introduction

Research school DISC is an interuniversity research institute and graduate school that unites all academic groups in the Netherlands that are active in systems and control theory and engineering. It offers a nationally organized graduate programme for PhD students in this field. Being founded by the Delft and Eindhoven Universities of Technology and the University of Twente, a majority of participants in the school are affiliated with the faculties of electrical engineering, mechanical engineering, and mathematics of these three universities. A large number of other departments and institutes participate in DISC under various agreements.

goals

The ambitions of DISC are:

- To provide a PhD programme of high quality and internationally recognized level;
- To provide PhD students with a national and international network and to support them in their development towards independent researchers that are part of the international community and whose research is recognized according to international standards;
- To develop the field of systems and control through coordinated research in both fundamental and technology directed programs, and to represent this field of science in national and international networks, consortia and boards;
- To use the position of DISC as center of expertise for dissemination of knowledge on systems and control theory and engineering in the widest sense.

research program

The research program of DISC consists of fundamental and applied scientific research in the domain of systems and control theory and engineering.
By exploiting the fundamental principle of feedback, control systems enable the realization of high-tech systems in all domains of engineering science with fascinating performance in terms of speed, accuracy, autonomy and adaptability to varying circumstances.
Modelling tools are essential in analysing and designing optimal control strategies. Mathematical System Theory provides insight in the formulation of mathematical models, in the derivation of models from experimental data, and in the design of control and feedback signals.

The research program of DISC is divided in three main areas, each of which contains several themes.

1. **System and control theory**
   - System theory, nonlinear, distributed, hybrid and embedded systems;
   - Control theory for nonlinear, robust, adaptive and optimal control.

2. **Theory and application of system modelling**
   - System identification, estimation and signal processing; detection and diagnosis;
   - Modelling tools: discrete events, hybrid systems, network theory, variational and geometric methods, fuzzy logic/neural networks.

3. **Applications of control engineering**
   - Mechatronics, robotics, precision technology, motion control systems, biomedical, aerospace and transportation systems;
   - Process control and optimization in (petro)-chemical and agricultural systems; analysis and control of biological systems.

teaching program

Through its graduate school DISC provides a program for graduate studies in systems and control offered to PhD students of the participating departments. Completing the 4-year programme of the graduate school leads to a PhD degree awarded by one of the participating universities. This programme is generally composed of a course program and a research project, leading to a PhD thesis to be defended in front of a thesis defense committee.

Educational activities of disc include:

Graduate courses on systems and control, organized in Utrecht, on a weekly basis (4 hrs/week), and lectured by national and international top lecturers.

A yearly 4-day international summer school on a particular topic or research field addressing recent developments within or relevant for systems and control.

A yearly winter course on a particular topic or research field lectured by an international lecturer.

Regular scientific DISC meetings where PhD students present their research results. The most important one is the yearly Benelux Meeting on Systems and Control, organized in cooperation with our Belgian colleagues.

msc education

Besides the PhD program in systems and control, DISC is represented in two interuniversity/national MSc programs: the national MSc program in Mathematics, and the 3TU MSc program in Systems and Control.

organization

DISC is governed by a board consisting of representatives of the 3TU's, the other universities, and an external member. The daily operation of DISC is directed by the scientific director, who is assisted by the DISC secretariat.
The DISC advisory board, composed of leading representatives from industrial, university and societal bodies, meets once a year with the DISC board to discuss issues concerning strategy and policy.
The scientific director is supported by a management team consisting of all heads of DISC departments.

participation and relationships

Research groups of DISC participate in many consortia and networks with academic, institutional and industrial partners.
Under the umbrella of DISC, all 3TU groups are involved in the 3TU Centre of Competence/Excellence
High Tech Systems/Intelligent Mechatronic Systems that has started in 2007 on the basis of a five-year grant from the Ministeries of Education and Economic Affairs.
Scientific Director of the 3TU Centre of Excellence is Prof. Maarten Steinbuch, TU/e-ME.

In conjunction with the Royal Institution of Engineers in The Netherlands (KIVI), DISC has the status of national member organization (NMO) of IFAC, the International Federation of Automatic Control.

systems and control

Systems theory and control technology forms an academic discipline that originates from the fields of electrical and mechanical engineering and mathematics. The field has also found its way in other technical areas, in biology, medical technology, agricultural science, economics, and computer science.

systems and control field

DISC unites all academic research in the Netherlands in the field of systems and control, ranging from mathematical systems theory research to technology-driven control engineering. Mechanical manipulation of hard-disk heads, developing energy-efficient greenhouses, designing cars that drive-by-wire, autonomously walking or flying robots, operational strategies in process industry .... in all these examples systems and control theory plays a crucial role.

By exploiting the fundamental principle of feedback, control systems enable the realization of high-tech systems in all domains of engineering science with fascinating performance in terms of speed, accuracy, autonomy and adaptability to varying circumstances. Without feedback man would literally fall down.
As a field of generic tools that facilitate modelling, control, design and optimization of technological dynamical systems, the systems and control field is providing a strong enabling technology that plays a central role in very many disciplines in science and engineering.

research program

The research program of DISC consists of fundamental and applied scientific research in the domain of systems and control theory and engineering. The research domain employs modern techniques from information and computer technology to analyse, control and optimize dynamical processes, machines and (high-tech) systems. Modelling tools are essential in analysing and designing optimal control strategies, e.g. by exploiting optimization theory. Mathematical System Theory provides insight in the formulation of mathematical models, in the derivation of mathematical models from experimental data, and in the design of control and feedback signals.

The orientation towards a variety of technological application domains is important for the interplay between theoretical possibilities on the one side, and the urge to advance high-tech applications on the other side, thereby providing a fruitful stimulus for further evolution and development of the scientific area.

research themes

The three main areas in the research programme of DISC are further divided into several themes. Within each theme research lines and topics are sketched together with the acronyms of the DISC groups that participate.

1. System and control theory

System theory, nonlinear, distributed, hybrid and embedded systems

- Behavioural systems and control theory (RUG-JBI, UT-AM, TU/e-EE)
- Infinite-dimensional systems (UT-AM, WU, TU/e-EE, RUG-JBI)
- Hybrid systems (RUG-JBI, CWI, TU/e-ME, TUD-DCSC, UT-AM)
- Embedded systems (TU/e-ME, RUG-JBI)
- Nonlinear systems and control theory (RUG-ITEM, TU/e-ME, TUD-DCSC, RUG-JBI)
- Model reduction (RUG-ENTEG, MU, TU/e-EE)

Control theory for nonlinear, robust, adaptive and optimal control

- Optimization-based control and LMI's (TUD-DCSC, TU/e-EE)
- Distributed sensing and control (TUD-DCSC, TU/e-EE, TU/e-ME)
- Adaptive control and learning (TUD-DCSC, TU/e-ME, TUD-AE)
- Nonlinear control (TU/e-ME, RUG-JBI)

2. Theory and application of system modelling

System identification, estimation and signal processing; detection and diagnosis

- System identification (TUD-DCSC, TU/e-EE, WU, CWI, MU)
- Fault detection (TUD-DCSC, TUD-AE)
- Parameter and state estimation (TUD-DCSC, WU, TUD-DIAM, TUD-AE)

Modelling tools: discrete events, hybrid systems, network theory, variational and geometric methods, fuzzy logic/neural networks

- Discrete event and hybrid systems (TU/e-ME, TUD-DCSC, TUD-DIAM, MU)
- Fuzzy systems and neural networks (TUD-DCSC)
- Physical modelling (RUG-JBI, TUD-DIAM, RUG-ENTEG)
- Financial engineering (TiU, UT-AM)

3. Applications of control engineering

Mechatronics, robotics, precision technology, motion control systems, biomedical, aerospace and transportation systems

- Mechatronics (TU/e-ME, TU/e-EE, TUD-DCSC, UT-EE, UT-ME, RUG-ENTEG)
- Aerospace systems (TUD-AE, TUD-DCSC)
- Transportation systems (TU/e-EE, TUD-DCSC)
- Smart optics systems (TUD-DCSC, TU/e-ME)
- Automotive systems (TU/e-ME, TUD-DCSC, TU/e-EE)

- Robotics (UT-EE, TUD-DCSC, TU/e-ME)
- Biomedical systems (TU/e-ME)
- Precision technology (TU/e-ME, TU/e-EE)
- Wind energy systems (TUD-DCSC)

Process control and optimization in (petro)-chemical and agricultural systems; analysis and control of biological systems

- Process control and optimization (TU/e-EE, TUD-DCSC, WU)
- Experiment design and monitoring (TUD-DCSC, WU)
- Biological systems (CWI, WU, TUD-DCSC, MU, RUG-JBI, RUG-ENTEG)
- Agricultural systems (WU, UT-AM)
- Nuclear fusion (TU/e-ME)

the graduate school of systems and control

introduction

**Through its graduate school DISC provides a program for graduate studies in systems and control offered to PhD students of the participating departments.
This graduate program runs since 1987 and is formally accredited by the Royal Dutch Academy of Sciences (KNAW), and since 2010 supported by NWO, in the scope of the NWO Graduate Programme.**

PhD students are offered a course program of weekly lectures that are given by top specialists in a central location in Utrecht. The courses cover a wide range of topics from mathematical systems theory to control engineering and intend to bring PhD students in short time to an internationally recognized research level.

Currently DISC involves around 100 tenured researchers, 20 post-docs and 200 PhD students in 15 DISC departments.

teaching program

DISC offers a graduate program in systems and control that leads to a doctorate degree of one of the participating universities. The requirements are:
Completion of a course program of 27 ECTS credits.
Completion of a doctoral dissertation, to be approved by the adviser and to be defended in front of an academic committee.

admission

Applications for PhD-membership of DISC are open to all PhD students that are supervised by an advisor who is a member of DISC. Admission to DISC requires an MSc degree in engineering, mathematics or science (to be approved by the university that grants the doctoral degree), an excellent academic record and a good motivation. PhD students are usually employed by the departments that participate in DISC and have a standard government appointment (research assistantship) for 4 years. PhD students of DISC groups should register for DISC by completing the student registration form.

International students that are interested in a graduate program in systems and control in the Netherlands have the following options:

- Apply for an advertized PhDposition in one of the DISC departments. Check the websites of the several DISC departments and the DISC site. These positions provide full financial support for the DISC graduate program.
- For students that already have a scholarship with full financial support it is advised to contact one of the DISC departments for admission to the graduate program.

Instutions that provide scholarships for graduate studies in the Netherlands are e.g.:
nuffic http://www.nuffic.nl/.
There is no tuition fee for PhD students in the Netherlands.

For certain EU-funded research projects EU citizenship is required. International PhD students usually manage very well in The Netherlands provided that they speak the English language sufficiently well.

DISC does not have a centralized application procedure. Recruitment of PhD students is done locally by the various DISC groups. There are continuously openings for PhD positions. Potential applicants are advized to approach any research group of their interest directly to enquire about any openings.

the course program

The course program of each DISC PhD student is arranged in consultation with the student's adviser and supervisory committee and is formalized in each student's education and supervision plan. It may consist of courses offered by DISC and of suitable graduate courses provided by related graduate schools and institutes.
Yearly organized summer schools and winter courses are part of the DISC graduate program, as well as yearly participation in the Benelux Meeting on Systems and Control, that offers PhD students a platform for presentation and discussion of their results in an international setting.

At the Benelux Meeting on Systems and Control special attention is given to the presentation skills of students, through the competition for the Best Junior Presentation Award.

The course program of DISC is organized in 3 periods (trimesters). All courses are offered as independent modules, so that PhD students can start in any of the three trimesters. The course programme consists of a set of basic courses (6 ECTS) and a number of specialized short courses (3 ECTS). Usually, the basic courses are scheduled yearly, while the specialized short courses vary each year.

Examples of basic courses are:

- *Mathematical Models of Systems*
- *Design Methods for Control Systems*
- *System Identification for Control*

Examples of specialized courses that have been provided regularly in the past are

- *Model Predictive Control*
- *Linear Matrix Inequalities in Control*
- *Modeling and Control of Hybrid Systems*
- *Nonlinear Control Systems*

The course program may be completed in 12 months. It consists of four basic courses and a number of specialized courses.

This year’s course program with schedule and timetable can be found on page 14. The descriptions of the courses you can find on page 16 and further.

The course program of DISC is (roughly) organized in three 8-week trimesters per year (September-October; November-January; March-April). In these periods courses are organized one day a week on

Mondays in a central location in Utrecht. In general two courses run in parralel: one morning course (10.15h-12.30h) and one afternoon course (13.45h-16.00h). The courses are given in the lecture rooms of Hogeschool Domstad, which is located on a short walk from Utrecht Central Station.

All courses provide the students with homework sets that have to be handed in timely for formal completion of the course and for obtaining a grade. Full credit points are only awarded to students that have attended the lectures of the course (auditing) and that have completed the homework sets with a sufficient grade. Auditing a course only (without handing in the homework sets) is rewarded with a reduced-rate ECTS: 1 credit for a 4-week course and 1,5 credit for a 8-week course. In order to receive credits all lectures should be attended. Exemption can only be made by informing the DISC secretariat in writing. All courses are taught in English.

fees and registration

The fee for taking or auditing a full DISC course is EUR 450,-. The fee is waived for registered DISC students/members. Participants can register on the DISC website https://disc-forum.nl or send an email to the DISC secretariat at secr@disc.tudelft.nl. Information about the DISC courses can be found on the DISC website www.disc.tudelft.nl.

grades, credits and certificate

For each completed course participants receive a written acknowledgement of participation that includes the obtained grade and the awarded credits. A DISC-certificate is handed out when 27 ECTS are completed, of which at least 13.5 ECTS are obtained on the basis of DISC-courses, maximally 12 ECTS are obtained through courses of other graduate schools that have cooperation agreements with DISC (ASCI, IPA, JMBC, OSPT, Trail), and maximally 6 ECTS are obtained through other courses that are approved by the research supervisor.

summer school

Every year DISC organizes a Summer School to familiarize students with a research topic of current interest. International specialists are invited to lecture in these summer schools. Recently organized schools are “Data-driven Modeling for Control” (2014) and “Control for Cyber-Physical Systems (2015)”.

winter course

Since 2009 DISC organizes a Winter Course, lectured by an international guest lecturer on a particular topic or research field relevant for systems and control. The course is typically scheduled in February and can be organized in one or more university locations. In 2011 Prof. Volker Mehrman lectured on “Modelling, simulation, control and optimization with differential-algebraic systems” and in 2012 Dr. Vincent Andrieu lectured on “Observer for Nonlinear Systems”.The winter course 2015-2016 is tentatively scheduled for February 2016.

benelux meeting on systems and control

The annual Benelux Meetings on Systems and Control are held alternately in The Netherlands and Belgium. They provide graduate students and researchers with a podium to present and discuss research results. The program includes keynote talks by invited international speakers and one or two mini-courses by senior researchers. Since 1996 the Best Junior Presentation Award is anually awarded for the best presentation by a PhD student. The Benelux Meeting 2016 will be held in The Netherlands from March 22-24, 2016.

best thesis award

The DISC PhD Thesis Award is awarded anually to the PhD candidate that has defended a PhD thesis under supervision of one of the professors of DISC, and that has been selected as the best thesis by a qualified jury. The award consists of a framed certificate and a monetary present, and is announced during the Benelux Meeting. Eligible candidates have completed their thesis defense within 54 months after the start of their project, have obtained a DISC certificate of the graduate programme, and are nominated by their supervisor.

nwo graduate programme

The DISC graduate programme is recognized by the Dutch Science Foundation (NWO) in view of the NWO Graduate Programme. In the scope of this NWO programme four junior DISC researchers have received scholarships for executing self-defined 4-year PhD projects.

course location

DISC courses are given in Cursus- en Vergadercentrum Domstad in Utrecht. It is located near the Utrecht-CS central railway station. For route descriptions see website www.accommodatiedomstad.nl.

course program 2015 – 2016

term	dates	morning	dates	afternoon
Fall 2015	7/9 14/9 21/9 28/9	**Adaptive Control** S. Baldi P. Tesi		
	2/11 9/11 16/11 23/11	**Constructive Lyapunov Methods for Stability Analysis of Dynamical Systems** M. Lazar N. Athanasopoulos	9/11* 16/11* 23/11*	**Energy-Based Modeling for Control of Physical Systems** A.J. van der Schaft D. Jeltsema
Winter 2015-2016	30/11 4/1 11/1	**Design Methods for Control Systems** M. Steinbuch G. Meinsma	30/11 **7/12** 4/1 11/1	**Nonlinear Control Systems** C. De Persis B. Jayawardhana
	18/1 25/1 1/2 15/2		18/1 25/1 1/2 15/2	**Distributed Control and Optimization in Multi-Agent Systems** T. Keviczky M.Cao
Spring 2016	7/3 14/3 21/3 4/4 **25/4** 2/5 9/5 23/5	**Mathematical Models of Systems** J.W. Polderman K. Camlibel	7/3 14/3 21/3 4/4 **18/4** 2/5 9/5 23/5	**System Identification for Control** P. M.J. Van den Hof X.J.A. Bombois

time table and location

Morning	10.15 - 11.15 11.30 - 12.30	**Location**	Cursus- en Vergadercentrum Domstad Koningsbergerstraat 9 3531 AJ Utrecht Phone: 030-2927777 www.accommodatiedomstad.nl
Afternoon	13.45 - 14.45 15.00 - 16.00 (17.00*)		

course descriptions
2015 - 2016

adaptive control

lecturers

Dr. S. Baldi, Delft University of Technology
Dr. P. Tesi, University of Groningen

objectives

Adaptive control covers a set of techniques which pro-vide a systematic approach for automatic adjustment of the controllers in real time, in order to achieve or to maintain a desired level of performance of the con-trol system when the parameters of the plant dynamic model are unknown and/or change in time.
While the design of a conventional feedback con-trol system is oriented firstly toward the elimination of the effect of disturbances upon the controlled variables, the design of adaptive control systems is oriented firstly toward the elimination of the effect of parameter dis-turbances upon the performance of the control system. An adaptive control system can be interpreted as a hi-erarchical system composed of a conventional feedback control and an adaptation loop.

The course presents a basic ground for analysis and design of adaptive control systems: it covers both es-tablished adaptive schemes based on continuous adap-tation, and more recent logic-based adaptive schemes with discontinuous adaptation. The course is organized as follows: after an initiation to parameter adaptation algorithms, Model Reference Adaptive Control (MRAC) and Self-Tuning Control (STC) schemes constitute the core of the adaptive schemes based on continuous adap-tation. Stability analysis in a deterministic environment (for the MRAC scheme) and convergence analysis in a stochastic environment (for the STC scheme) are both dealt with. The final part of the course is constituted by Adaptive Switching Control (ASC) schemes, which have emerged as an alternative to conventional contin-uous adaptation. ASC schemes embody a supervisory logic that performs adaptation tasks based on plant input/output data. Different families of logic-based adaptive control schemes will be introduced, includ-ing multiple-model ASC schemes, which offer, among other properties, the possibility to combine features from robust and conventional adaptive control
At the end of the course the student should be able to:

- Design, simulate, and implement parameter adap-tation schemes;
- Design, simulate, and implement adaptive control schemes;
- Master the main analytical details in stability and convergence proofs of adaptive control schemes;
- Compare different adaptive control methodolo-gies;
- Discuss simulation results.

contents

Lecture 1 - Introduction and parameter adaptation

- Introduction to adaptive control
- Linear parametric models
- Gradient and least square algorithms

- Robust parameter adaptation laws (elements)

Lecture 2 - Model Reference Adaptive Control (MRAC)

- Model Reference Control with known parameters
- Direct/Indirect MRAC schemes
- Instability examples
- Robust MRAC schemes (elements)

Lecture 3 - Self-Tuning Control (STC)

- Adaptive prediction in the stochastic setting
- Stochastic single-step regulation
- Minimum-variance STC
- Generalized minimum-variance STC

Lecture 4 - Adaptive Switching Control (ASC)

- Introduction to ASC
- Logic-based supervisors
- Multi-Model ASC

course material

1. Landau I. D., Lozano R., M'Saad M., and Karimi A., Adaptive Control: Algorithms, Analysis and Ap-plications, 2nd edition, Springer-Verlag, 2011..
2. Ioannou P. A. and Fidan B., Adaptive Control Tuto-rial, SIAM, 2006.
3. Mosca E., Optimal, Predictive, and Adaptive Con-trol, Prentice Hall, 1995.4. G. Balas, R. Chiang, et al. (2006). Robust Control Toobox (Version 3.1), The MathWorks Inc.

Additional material distributed during the course.

prerequisites

Notions of linear systems theory, Lyapunov stability and stochastic processes at the intermediate level. Extra course material on these topics will be provided to take into account different entry levels. Basic MATLAB pro-gramming skills are also required

homework assignments

Two homework assignments, each one accounting for 50% of the final grade. The homework assignments, distributed at the end of the second and the fourth lecture, will consist of both mathematical and program-ming problem solving exercises

constructive Lyapunov methods for stability analysis of dynamical systems

lecturers

Dr. M. Lazar, Eindhoven University of Technology
Dr. N. Athanasopoulos, Université catholique de Louvain

objective

In real-life applications it is of utmost importance to guarantee safe operation of a system for a desired operating range. To this end, stability and domain of attraction are useful concepts. This course will provide a theoretical basis for Lyapunov stability theory for discrete-time nonlinear systems and contractive set theory for discrete-time homogeneous systems, respectively. In both Lyapunov and set theoretical frameworks, the classical theorems and algorithms will be worked out and new, less conservative finite-time theorems and algorithms will be presented. The notions of Minkowski function and proper C-set will be used to establish equivalence between Lyapunov functions and contractive sets for homogeneous systems. Numerical algorithms for constructing Lyapunov functions and contractive sets will be worked out for the following types of discrete-time system dynamics: linear, switched linear with arbitrary switching and switched linear with state-dependent switching and rule-dependent switching. All developed methods will be illustrated on several examples.

contents

Lecture 1 Lyapunov stability theory: KL stability, Lyapunov functions, Lyapunov's theorem, finite-time Lyapunov functions, converse Lyapunov theorem, domain of attraction.
Lecture 2 Contractive set theory: proper C-sets, Minkowski functions, contractive sets, finite-time contractive sets, equivalence of Minkowski Lyapunov functions and contractive proper C-sets.
Lecture 3 Switched linear dynamics: Construction of piecewise quadratic and piecewise linear Lyapunov functions, construction of finite-time Lyapunov functions.
Lecture 4 Switched linear dynamics: Construction of contractive proper C-sets by forward and backward set-iterates, construction of finite-time contractive proper C-sets.

lecture notes

A selection of articles will be recommended for reading for each lecture along with the lecture handouts.

prerequisites

Linear algebra, Continuous functions, Basic knowledge of Lyapunov stability theory and Systems theory, Convex optimization, Matlab MPT Toolbox. A set of appendices that contain a compact summary of prerequisite knowledge will be available for download.

homework assignments

The participants will be asked to complete a composite homework assignment.

energy-based modeling for control of physical systems

lecturers

Dr.ing. D. Jeltsema, MSc, Delft University of Technology
Prof.dr. A.J. van der Schaft, University of Groningen

objectives

This course presents a variety of modeling techniques that uses energy as a starting point. Apart from the fact that energy is a fundamental concept in physics, there are several motivations for adopting an energy-based perspective in modeling physical systems. First, since a physical system can be viewed as a set of simpler subsystems that exchange energy among themselves and the environment, it is common to view dynamical systems as energy-transformation devices. Secondly, energy is neither allied to a particular physical domain nor restricted to linear elements and systems. In fact, energies from different domains can be combined simply by adding up the individual energy contributions. Thirdly, energy can serve as a lingua franca to facilitate communication among scientists and engineers from different fields. Lastly, the role of energy and the interconnections between subsystems provide the basis for various control strategies.

contents

First we start with the basic concepts of port-based network modeling, where complex lumped- parameter multiphysics systems are systematically modeled as networks of ideal components linked by energy-flow. We show how this immediately leads to a differential equation representation that is in generalized Hamiltonian form, including the standard conservative Hamiltonian systems based on the exchange of energy between different energy storages; e.g., in the mechanical domain between potential and kinetic energy. Furthermore, we discuss how the port-Hamiltonian representation leads to other useful representations such as the Brayton-Moser equations. We show how port-Hamiltonian models not only reflect the energy flow in the system, but also capture the other basic physical conservation laws, such as conservation of momentum or charge. This will be amply illustrated on a number of applications stemming from mechanics, mechatronics, hydraulic systems, MEMS, and power systems. We also show how distributed-parameter (partial-differential equation) components are incorporated in this broadly applicable modeling approach to nonlinear multi-physics systems.

schedule

Week 1: General introduction to port-based modeling.
Week 2: Port-Hamiltonian systems.
Week 3: Distributed-parameter systems and other extensions..

course material

• A.J. van der Schaft, "Port-Hamiltonian differential-algebraic systems", pp. 173--226 in Surveys in Differential-Algebraic Equations I (eds. A. Ilchmann, T. Reis), Differential-Algebraic Equations Forum, Springer, 2013.
• D. Jeltsema and J.M.A. Scherpen, “Multi-domain modeling of nonlinear networks and systems: energy- and power-based perspectives”, in August edition of IEEE Control Systems Magazine, pp. 28-59, 2009.
• A.J. van der Schaft, A comprehensive introduction to port-Hamiltonian systems, to be written.
• Hand-outs. To be distributed during the course.

prerequisites

Calculus and linear algebra. Elementary physics. Some knowledge of systems theory is helpful, but not required.

examination

Two case studies will be handed out during the course. The average grade of these two assignments determines the final grade. There is no final exam.

design methods for control systems

lecturers

Prof.dr.ir. M. Steinbuch, Eindhoven University of Technology
Dr.ir. G. Meinsma, University of Twente

objective

The course presents "classical," "modern" and "post modern" notions about linear control system design. First the basic principles, potentials, advantages, pitfalls and limitations of feedback control are presented. An effort is made to explain the fundamental design aspects of stability, performance and robustness.

Next, various well-known classical single-loop control system design methods, including Quantitative Feedback Theory, are reviewed and their strengths and weaknesses are analyzed.
The course includes a survey of design aspects that are characteristic for multivariable systems, such as interaction, decoupling and input-output pairing. Further LQ, LQG and some of their extensions are reviewed. Their potential for single- and multi-loop design is examined.

After a thorough presentation of structured and unstructured uncertainty, model design methods based on H-infinity-optimization (in particular, the mixed sensitivity problem and McFarlane-Glover's loopshaping problem) and mu-synthesis are presented.

contents

1. Introduction to feedback theory. Basic feedback theory, closed-loop stability, stability robustness, loop shaping, limits of performance.
2. Classical control system design. Design goals and classical performance criteria, integral control, frequency response analysis, compensator design, classical methods for compensator design. Quantitative Feedback Theory.
3. Multivariable Control Multivariable poles and zeros, interaction, interaction measures, decoupling, input-output pairing, servo compensators.
4. LQ, LQG and Control System DesignLQ basic theory, some extensions of LQ theory, design by LQ theory, LQG basic theory, asymptotic analysis, design by LQG theory, optimization, examples and applications.
5. Uncertainty models and robustnessParametric robustness analysis, the basic perturbation model, the small-gain theorem, stability robustness of the basic perturbation model, stability robustness of feedback systems, numerator-denominator perturbations, structured singular value robustness analysis, combined performance and stability robustness.
6. H-infinity optimization and mu-synthesis The mixed sensitivity problem, loop shaping, the standard H-infinity control problem, state space solution, optimal and suboptimal solutions,

integral control and HF roll-off, mu-synthesis, application of mu-synthesis.

a. Appendix on Matrices
b. Appendix on norms of signals and systems

prerequisites

Basic undergraduate courses in systems and control. Some familiarity with MATLAB is helpful for doing the homework exercises.

lecture notes

A full set of lecture notes will be made available on the course website: disc-forum.nl.

homework assignments

Four homework sets will be distributed via the course website. Homework is graded on a scale from 1 to 10. Missing sets receive the grade 1. The final grade for the course is the average of the grades for the four homework sets

nonlinear control systems

lecturers

Prof. dr. C. De Persis, University of Groningen
Prof. dr. B. Jayawardhana, University of Groningen

objective

The course aims at introducing basic properties of nonlinear systems, fundamental stability notions in nonlinear systems and a set of self-contained results on the control design of nonlinear systems.

contents

Lecture 1 (Introduction to nonlinear systems). During this lecture, the students will be given examples on nonlinear systems, and several fundamental properties and stability notions of nonlinear systems will be introduced.
References
H. Khalil, *Nonlinear Systems*, 3rd edition, Prentice Hall, 2002, Chapter 1, 2, and 3.

Lecture 2 (Lyapunov stability). The students will learn Lyapunov converse theorem and characterization of input-to-state stability notion.
References
H. Khalil, *Nonlinear Systems*, 3rd edition, Prentice Hall, 2002, Section 4.7 – 4.9.
E.D. Sontag, "Input to state stability: basic concepts and results," P. Nistri & G. Stefani (eds.), Nonlinear and Optimal Control Theory, pp. 163-220, Springer-Verlag, Berlin, 2006.

Lecture 3 (Feedback linearization). In this lecture, the students will be introduced to the concept of relative-degree and normal forms. The application of these notions to feedback linearization and for control design will be given.
References
H. Khalil, *Nonlinear Systems*, 3rd edition, Prentice Hall, 2002, Chapter 13.

Lecture 4 (Nonlinear control design). During this lecture, the students will learn the backstepping control design approach.
References
H. Khalil, *Nonlinear Systems*, 3rd edition, Prentice Hall, 2002, Section 14.3.

lecture notes

The lecture notes will be distributed during the course.

prerequisites

The students are expected to be familiar with ordinary differential equations,
linear control systems and linear algebra.

homework assignments

A set of homework assignments will be distributed at the end of each lecture.

distributed control and optimization in multi-agent systems

lecturers

Dr.ir. T. Keviczky, Delft University of Technology
Prof.dr. M. Cao, University of Groningen

objective

The purpose of this course is to overview distributed consensus and optimization algorithms and their applications in multi-vehicle cooperative control. Theoretical results on distributed consensus algorithms for multi-agent systems are first introduced. This is followed by an overview of distributed optimization techniques and corresponding decomposition methods along with optimizationbased control design approaches such as distributed MPC. Application examples are then investigated where the distributed algorithms are used for coordinating vehicle formations (composed of wheeled and airborne mobile robots or deepspace spacecraft), and performing tasks such as rendezvous and formation keeping.

contents

1. Overview of recent research on distributed multi-vehicle cooperative control.
2. Consensus algorithms for singleand double-integrator dynamics. Specifically, we introduce basic consensus algorithms for singleintegrator dynamics, consensus tracking of a dynamic leader, consensus algorithms for doubleintegrator dynamics, consensus under realistic constraints, and swarm tracking algorithms.
3. Distributed optimization methods and various decomposition techniques (primal, dual, augmented Lagrangian / proximal point method), links to consensus algorithms, and their application in networked multi-vehicle distributed robotics problems.
4. Online optimization-based control approaches such as distributed model predictive control for multivehicle cooperation, distributed LQR and decomposition based methods that are applicable to collections of identical mobile agents.
The presented topics are illustrated on cooperative rendezvous, distributed formation control, spacecraft formation flight, and other application examples in robotic networks.

prerequisites

Basic background in systems and control theory.

lecture notes

Will be distributed during the course.

homework assignments

Four homework sets will be distributed by the course website. Homework is graded on a scale from 1 to 10. Missing sets receive the grade 1. The final grade for the course is the average of the grades for the four homework sets.

mathematical models of systems

lecturers

Dr. J.W. Polderman, University of Twente
Prof. dr. K. Camlibel, University of Groningen

objective

The purpose of this course is to discuss the ideas and principles behind modelling
using the behavioral approach, and to apply these ideas to control system design.
In the behavioral approach, dynamical models are specified in a different way than is customary in transfer function or state space models. The main difference is that it does not start with an input/output representation. Instead, models are simply viewed as relations among certain variables. The collection of all time trajectories which the dynamical model allows is called the behavior of the system. Specifcation of the behavior is the outcome of a modelling process. Models obtained from first principles are usually set-up by tearing and zooming. Thus the model will consist of the laws of the subsystems on the one hand, and the interconnection laws on the other. In such a situation it is natural to distinguish between two types of variables: the manifest variables which are the variables which the model aims at, and the latent variables which are aux-iliary variables introduced in the modelling process. Behavioral models easily accommodate static relations in addition to the dynamic ones. A number of system representation questions occur in this framework, among others:

- the elimination of latent variables
- input/output structures
- state space representations

We will also introduce some important system properties as controllability and observability in this setting.
In the first part of the course, we will review the main representations, their interrelations, and their basic properties. In the context of control, we will view interconnection as the basic principle of design. In the to-be-controlled plant there are certain control terminals and the controller imposes additional laws on these terminal variables. Thus the controlled system has to obey the laws of both the plant and the controller. Control design procedures thus consist of algorithms which associate with a specifcation of the plant (for example, a kernel, an image, or a hybrid representation involving latent variables) a specifcation of the controller, thus passing directly from the plant model to the controller. We will extensively discuss the notion of implementability as a concept to characterize the limits of performance of a plant to be controlled. We will discuss how the problems of pole-placement and stabilization look like in this setting.

contents

1. General ideas. Mathematical models of systems. Dynamical systems. Examples from physics and economics. Linear time-

invariant systems. Differential equations. Polynomial matrices.
2. Minimal and full row rank representation. Autonomous systems. Inputs and outputs. Equivalence of representations.
3. Differential systems with latent variables. State space models. I/S/O models.
4. Controllability. Controllable part. Observability.
5. Elimination of latent variables. Elimination of state variables.
6. From I/O to I/S/O models. Image representations.
7. Interconnection. Control in a behavioral setting. Implementability
8. Stability. Stabilization and pole placement.

prerequisites

The course is pretty much self-contained. Basic linear algebra and calculus should suffice..

course material

The main reference is Introduction to Mathematical Systems Theory: A Behavioral Approach by J.W. Polderman and J.C. Willems (Springer 1998 as e-book). /
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system identification for control

lecturers

Prof.dr.ir. P.M.J. Van den Hof, Eindhoven University of Technology
Dr.ir. X.J.A. Bombois, Laboratoire Ampère, École Centrale de Lyon, France

objectives

System Identification concerns the modeling of dynamical systems on the basis of observed data. The objective of this course is to present the important system identification techniques with a special attention to prediction error methods. Subspace and frequency-domain methods will be covered as well. We will consider both the cases of data collected in open loop and data collected in closed loop. Finally, the problem of the optimal design of the identification experiment will be addressed.

contents

1. Introduction; concepts; discrete-time signal and system analysis
2. Parametric (prediction error) identification methods - model sets, identification criterion, statistical properties
3. Parametric (prediction error) identification methods - model validation, experiment design and approximate modelling
4. ETFE and frequency-domain identification
5. Closed-loop identification
6. Optimal identification experiment design
7. Extension on model structures and identification methods
8. Subspace identification

prerequisites

Calculus and linear algebra. Some knowledge of statistics and linear systems theory and/or time series analysis is helpful, but not required. The lecture notes contain useful summaries of the important notions used during the course.

lecture notes

Lecture notes will be distributed during the course.

course assessment

The assessment of this course will be in the form of three homework assignments.

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