information brochure 2017-2018 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 administrative 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 4TU MSc program in Systems and Control.

organization

DISC is governed by a board consisting of representatives of the three technical universities and the other universities. 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.

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-ENTEG, 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, UT-BE)
- Biomedical systems (TU/e-ME, UT-BE)
- 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 115 tenured researchers, 30 post-docs and 215 PhD students in 16 DISC departments participate in DISC.

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 three or 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 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).

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.

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.

fees and registration

The fee for taking or auditing a 3 ECTS DISC course is €250 and auditing or taking a 6 ECTS DISC course is € 450,-. The fee is waived for DISC students/members. Participants can register on the DISC course platform (http://disc-courseplatform.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 may be obtained through courses of other graduate schools and maximally 6 ECTS can be obtained through other (MSc) courses that are approved by the research supervisor.

Students who wish to obtain DISC credits for non-DISC courses are advised to contact the DISC secretariat beforehand so that the course(s) can be pre-approved.

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 “A Systems and Control Perspective in Human Robot Environment Interaction”(2016) and “A Systems and Control Perspective on Privacy, Safety, and Security in large-scale Cyber-Physical Systems” (2017).

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 the winter trimester and can be organized in one or more university locations. The topic of the wintercourse 2016-2017 was “System Identification in the Life Sciences” and it was hosted by

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 2018 will be held in Soesterberg, The Netherlands from March 27-29,2018.

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.

course program 2017 – 2018

term	dates	morning	afternoon
Fall 2017	4/9 11/9 18/9 25/9	**Model Reduction for Control, from Linear to Nonlinear Systems** J. Scherpen K. Fujimoto	**Adaptive control** S. Baldi P. Tesi
	9/10 16/10 23/10 30/10	(no morning course scheduled)	**Linear Matrix Inequalities in Control** S. Weiland R. Toth
Winter 2018	29/1 12/2 19/2 26/2	**Mathematical Models of Systems** J.W. Polderman H. Trentelman	**Nonlinear Control Systems** B. Jayawardhana B. Besselink
	5/3 12/3 19/3 26/3		**Multi-agent Network Dynamics and Games** M. Cao S. Grammatico
Spring 2018	9/4 16/4 23/4 30/4 7/5 14/5 28/5 4/6	**Design Methods for Control Systems** M. Steinbuch G. Meinsma	**System Identification** P. Van den Hof J. Schoukens G. Bottegal X. 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		

course descriptions
2017 - 2018

model reduction for control, from linear to nonlinear systems

lecturers

Prof. dr.ir. J.M.A. Scherpen, University of Groningen
Prof. dr. K. Fujimoto, Kyoto University, Japan

objectives

The purpose of this course is to provide a basis for model order reduction for control based on balanced realizations, and treats the use of these methods at different levels (more in depth or more at an initial stage) for various types of systems, varying from linear to nonlinear, from lumped to networked to distributed systems. The need for innovation results in a dominating trend towards analyzing and designing systems of increasing complexity. Such analysis and design cycles rely on the mathematical models of the systems. These models are thus increasing in complexity as well, both in nature (from linear to nonlinear, from lumped- to networked to distributed-parameter), and size. Complex models are more difficult to analyze and simulate. Due to this it is also difficult to develop and implement control algorithms; moreover high-order controllers are usually not wanted. This course will focus both on linear and nonlinear systems, and will provide a basis for studying and usage of balancing based model order reduction methods.

contents

1. A brief overview of recent model order reduction techniques for linear and nonlinear, networks and distributed parameter systems.
2. Balancing for linear systems is treated from a state-space point of view, and a relation with minimality and the frequency domain is given. The relation with the Hankel operator, and error bounds and their derivation are treated. Other types of balancing, closed-loop balancing, and balancing based on dissipativity, and passivity will be treated.
3. Frequency weighting, controller reduction methods, and network reduction methods based on balancing will be treated.
4. Extensions to nonlinear systems for balancing and the corresponding Hankel operator will be treated.
5. Applications for linear systems, and motivational examples for nonlinear systems will be considered

course material

The lecture notes will be distributed during the course.

prerequisites

Basic background in systems and control theory.

homework assignments

Two homework sets will be handed out. The average grade will be the final grade for this course.

adaptive control

lecturers

Dr. Simone Baldi, Delft University of Technology
Dr. Pietro Tesi, University of Florence

objectives

Adaptive control covers a set of techniques which provide 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 control system when the parameters of the plant dynamic model are unknown and/or change in time.

While the design of a conventional feedback control 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 disturbances upon the performance of the control system. An adaptive control system can be interpreted as a hierarchical 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 established adaptive schemes based on continuous adaptation, 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) schemes constitute the core of the adaptive schemes. MRAC is addressed both from a continuous adaptation point of view and in discontinuous environments, with emphasis on networked environments (switched dynamics and quantization phenomena). The final part of the course is constituted by Adaptive Switching Control (ASC) schemes, which have emerged as an alternative to conventional continuous 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, including 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 adaptation 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 methodologies;
-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 - Adaptive networked control
• Introduction to hybrid and switched systems (elements)
• Adaptive control of switched systems
• Adaptive quantized control

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 Applications, 2nd edition, Springer-Verlag, 2011.
2. Ioannou P. A. and Fidan B., Adaptive Control Tutorial, SIAM, 2006.

Additional material distributed during the course.

prerequisites

Notions of linear systems theory and Lyapunov stability at the intermediate level. Notions of hybrid systems might turn out useful as well. Extra course material on these topics will be provided to take into account different entry levels. Intermediate MATLAB programming 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 programming problem solving exercises.
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linear matrix inequalities in control

lecturers

Prof.dr. S. Weiland, Eindhoven University of Technology
Dr.ir. R. Toth, Eindhoven University of Technology

objective

Linear matrix inequalities (LMI's) have proven to be a powerful tool to approach control problems that appear hard if not impossible to solve in an analytic fashion. Although the history of LMI's goes back to the forties with a major emphasis of their role in control in the sixties (Kalman, Yakubovich, Popov, Willems), the present numerical interior point and semi-definite programming techniques are increasingly powerful to solve LMI's in a practically efficient manner (Nesterov, Nemirovskii 1994). Several Matlab software packages are available that allow a simple coding of general LMI problems that arise in typical control problems.
Because of the availability of fast and efficient solvers for semi-definite programs, the research in robust control has experienced a paradigm shift towards reformulating control problems in terms of feasibility tests of systems of LMI's where properties of convexity and semi definite programs are fully exploited to solve relevant problems in systems and control.

The main emphasis of the course is:

- to reveal the basic principles of formulating desired properties of a control system in the form of LMI's
- to demonstrate the techniques how to reduce the corresponding controller synthesis problem to an LMI problem.
- to get familiar with the use of software packages for performance analysis and controller synthesis using LMI tools.

The power of this approach is illustrated by several fundamental robustness and performance problems in analysis and design of linear control systems.

contents

1. Some facts from convex analysis. Linear Matrix Inequalities: Introduction. History. Algorithms for their solution.
2. The role of Lyapunov functions to ensure invariance, stability, performance, robust performance. Considered criteria: Dissipativity, integral quadratic constraints, H2-norm, H8-norm, upper bound of peak-to-peak norm. LMI stability regions.
3. Frequency domain techniques for the robustness analysis of a control system. Integral Quadratic Constraints. Multipliers. Relations to classical tests and to μ-theory.
4. A general technique to proceed from LMI analysis to LMI synthesis. State-feedback and outputfeedback synthesis algorithms for robust stability, nominal performance and robust performance using general scaling.
5. A choice of extensions to mixed control problems and to linear parametrically-varying controller

design, robust estimation problems or the use of multiplier techniques in control system design.

course material

The main reference material for the course will be an extensive set of lecture notes by Carsten Scherer and Siep Weiland. Additional reference material:

1. S. Boyd, L. El Ghaoui, E. Feron and V. Balakrishnan, Linear Matrix Inequalities in System and Control Theory, SIAM studies in Applied Mathematics, Philadelphia, 1994.
2. L. El Ghaoui and S.I.Niculescu (Editors), Advances in Linear Matrix Inequality Methods in Control, SIAM, Philadelphia, 2000.
3. A. Ben-Tal, A. Nemirovski, Lectures on Modern Convex Optimization: Analysis, Algorithms, and Engineering Applications, SIAM-MPS Series in Optimizaton, SIAM, Philadelphia, 2001.
4. G. Balas, R. Chiang, et al. (2006). Robust Control Toobox (Version 3.1), The MathWorks Inc.
5. J. Löfberg, YALMIP, http://control.ee.ethz.ch/˜joloef/yalmip.php.

prerequisites

Linear algebra, calculus, basic system theory, MATLAB.

homework assignments

We plan to issue 4 homework sets that include choices of theoretical and practical assignments. Full credit is received for successfully solving the assigned take-home sets.

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mathematical models of systems

lecturers

Dr. J.W. Polderman, University of Twente
Prof. dr. H. Trentelman, 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. Specification 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 auxiliary 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 that associate with a specification of the plant (for example, a kernel, an image, or a hybrid representation involving latent variables) a specification 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.

course materials

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).

prerequisites

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

nonlinear control systems

lecturers

Prof. dr. B. Jayawardhana, University of Groningen
Dr. B. Besselink, 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.

course materials

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.

multi-agent network dynamics and games

lecturers

Prof. dr. ir. M. Cao, University of Groningen
Dr. ing. S. Grammatico, Delft University of Technology

objective

The aim of the course is to introduce the mathematical tools for analyzing the dynamics of autonomous, rational agents that interact over and evolve on networks. Application examples will be drawn from several domains, such as power systems, smart grids, network congestion control, social networks, robotic and sensor networks.

The selected mathematical tools are within linear algebra, graph theory, fixed point and monotone operator theory, computational and evolutionary game theory.

contents

• Lecture 1: Introduction to network dynamics and games.
Elements of graph theory and game theory: directed and undirected graphs. Multi-player, aggregative and network, games. Application to decision-making dynamics in social networks.
• Lecture 2: Multi-agent systems: an operator theoretic perspective.
Elements of operator theory: fixed points, zeros, contraction, averaged and nonexpansive mappings. Fixed point algorithms: Banach iteration, Krasnoselskij iteration. Zero-finding algorithms: operator splitting, forward–backward algorithm. Application to network congestion control.
• Lecture 3: Introduction to evolutionary games.
Evolutionary stable strategies (ESS), social optimality, discrete-time vs. continuous-time models. Application to the modeling of emergence of cooperation in self-organized systems.
• Lecture 4: Propagation dynamics in multi-agent networks.
Linear threshold models, Markov chains, fast-slow dynamics. Applications to epidemic dynamics and behavioral propagation on complex networks.

course materials

The lecture slides and notes will be made available on the DISC course platform.

The main textbook references are the following.
[1] H. H. Bauschke and P. L. Combettes. Convex analysis and monotone operator theory in Hilbert spaces. Springer, 2010.
[2] N. Biggs. Algebraic Graph Theory. Cambridge University Press, 2nd edition, 1994.
[4] C. D. Godsil and G. F. Royle. Algebraic Graph Theory. Springer, 2001.
[5] R.T. Rockafellar and R.J.B. Wets. Variational Analysis. Springer, 1998.
[6] W. H. Sandholm. Population Games and Evolutionary Dynamics. MIT Press, 2010..

prerequisites

The students are expected to be

familiar with ordinary differential equations, linear control systems and linear algebra.

homework assignments

Homework assignments will be handed out and graded. Some homework assignments may be replaced by an elective simulation project on multi-agent network games.

design methods for control systems

lecturers

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

objective

The course presents "classical," "modern" and "postmodern" 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 DESIGN.
   LQ 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 ROBUSTNESS.
   Parametric 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.

lecture notes

A full set of lecture notes will be made available on the DISC course platform.

prerequisites

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

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.

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system identification

lecturers

Prof.dr.ir. P.M.J. Van den Hof, Eindhoven University of Technology
Prof.dr.ir. J. Schoukens, VUB, Brussels, Belgium
Prof.dr.ir. X. Bombois, CNRS, École Centrale de Lyon, France
Dr. G. Bottegal, Eindhoven University of Technology

objective

System Identification is involved with data-driven modeling of dynamical systems. The objective of this course is to present the important system identification techniques with a special attention to prediction error methods. Time- and frequency-domain methods will be covered, as well as parametric and non-parametric approaches, with particular attention for recently developed techniques in the domain of machine learning. While the focus will be on linear time-invariant systems, extensions will be made to nonlinear systems also. We will consider both the cases of open-loop and closed-loop data as well as problems of optimal experiment design.

contents

1. Introduction; concepts; discrete-time signal and system analysis; estimation
2. Parametric (prediction error): identification methods, model sets, identification criterion, statistical properties
3. Parametric (prediction error): identification methods, model validation, approximate modelling, Maximum likelihood and CRLB.
4. Regularization and non-parametric kernel-based identification; machine learning
5. Frequency-domain identification, parametric and non-parametric.
6. Nonlinear models
7. Optimal experiment design
8. Identification in closed-loop and dynamic networks.

course material

Lecture notes will be distributed during the course.

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.

homework assignments

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

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Unit DISC is the council of research students of DISC. It represents the group of PhD students and interacts with the scientific director and board of DISC on all matters that relate to DISC activities and the position of PhD students. They also take care of the course evaluations. Unit DISC can be contacted through one of their representatives:

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