information brochure 2016-2017 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.

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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 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.
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-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)
- 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 115 tenured researchers, 30 post-docs and 215 PhD students in 16 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 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 (September-November; December-February; March-June). 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 3 ECTS DISC course is €250 and auditing or taking a 6 ECTS DISC course is € 450,-. The fee is waived for registered 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 are obtained through courses of other graduate schools and maximally 6 ECTS are 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 "Control for Cyber-Physical Systems (2015)"and "A Systems and Control Perspective in Human Robot Environment Interaction"(2016).

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 wintercourse 2016 was on the topic of " Power Systems Control – from Circuits to Economics". The winter course 2016-2017 is tentatively scheduled for the first full week of December 2016 . The topic will be "Modelling in the Life Sciences" and it will be hosted by

Wageningen University

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 2017 will be held in Spa, Belgium from March 28-30, 2017.

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 2016 – 2017

term	dates	morning	afternoon
Fall 2016	7/11 14/11 21/11 28/11	**Linear Matrix Inequalities in Control** S. Weiland R. Toth	**Computational Linear Algebra: a least squares perspective** M. Verhaegen B. De Moor
Winter 2016-2017	16/1 23/1 30/1 6/2	**Mathematical Models of Systems** J.W. Polderman K. Camlibel	**Modeling and Control of Hybrid Systems** B. De Schutter W.P.M.H. Heemels
	13/2 20/2 27/2 6/3		**Nonlinear Control Systems** B. Jayawardhana B. Besselink
Spring 2017	20/3 27/3 3/4 10/4	**Design Methods for Control Systems** M. Steinbuch G. Meinsma	**Distributed Parameter Systems** H. Zwart A. Ran
	24/4 1/5 8/5 15/5		
	29/5* 12/06 19/06	**Automatic Verification and Synthesis of Complex Systems** M. Mazo A.Abate	

* the lecture of 29-5-2017 will take place in the morning and the afternoon.

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
2016 - 2017

linear matrix inequalities in control

lecturers

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

objectives

Linear matrix inequalities (LMI's) have emerged as 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 fourties 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 sufficiently 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 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.

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, H∞-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 scalings.
5. 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 lectures notes and

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.

computational linear algebra: a least squares perspective

lecturers

Prof. dr. ir. M. Verhaegen, Delft University of Technology
Prof. B. De Moor, KU Leuven

objectives

The computational aspects in solving fi identification and control problems is becoming more important with the event of embedded, cheap and general purpose control systems. Inspired by the evolution in hardware we observe an increase in the size of system theoretical problems that are analyzed in industry.
The numerical aspects of efficiency and accuracy in the designing numerical solutions is the driving force to computational linear algebra. The objective of this course is to show the use of linear algebra, its geometric interpretation and convex optimization in deriving new, simpler and easier to understand solutions to various system theoretical problems. In this course a number of key problems in system the- ory are formulated, solved and analyzed from a computational algebra perspective

contents

(a) Subspace identification (SI) of LTI systems
Basic linear algebra tools such as the QR factorization, the SVD and linear least squares problems allow to approximate structural information about LTI systems, such as the observability matrix, from input-output measurements. The latter data is assumed to be taken from an LTI system operating in open- loop. Different perturbation scenarios of the data are considered.
(b) Nuclear Norm convex optimization for identifying LTI systems
Subspace identification methods are characterized o.a. by the calculation of low rank approximation in order to retrive key subpsaces of interest. Generally the SVD is used for that purpose. New families of subspace identification methods have emerged that replace the SVD step by nuclear norm optimization. A brief introduction will be given to this new developement.
(c) Realization theory and distance measures between linear systems.
It turns out that there are important and surprising connections between system theory (stochastic realization, subspace principle angles, cepstral norm and distances), information theory (Shannon entropy and mutual information), statistics (canonical correlations) and signal processing (Kalman fi We will elaborate in detail on these connections, develop the relation with sub- space identification algorithms and show how these insights can be used in datamining, more specifically in the clustering of time series.
(d) Applications of realization theory, subspace identification and distance measures.
It is little known that there are numerous applications of realization theory and subspace identification. We will elaborate on fi the roots of

systems of multivariable polynomials in numerical algebraic geometry, fi
eigen- frequencies and modes in modal analysis in mechanical engineering, subspace modelling from power spectra, the so-called shape from moments problem in computer tomography and the modelling of textures in one and more dimensions. Several industrial examples of subspace identification will be discussed.

course material

Copies of all slides, and material contained in

- Book: M. Verhaegen and V. Verdult, "Filtering and System Identification: A least squares Approach", Cambridge University Press 2007.
- Book: Van Overschee P., De Moor B., Subspace Identification for Linear Systems: Theory, Implementation, Applications, Kluwer Academic Publishers, 1996, 254 p., Downloadable from http://homes.esat.kuleuven.be/sistawww/cgi- bin/pub.pl
- PhD Thesis: De Cock K., Principal Angles in System Theory, Information The- ory and Signal Processing, PhD thesis, Faculty of Engineering, KU Leuven (Leuven, Belgium), May 2002, 337 p.

Downloadable from http://homes.esat.kuleuven.be/sistawww/cgi-bin/pub.pl..

prerequisites

A master's degree in engineering with specialisation in signal, systems and/or control.

homework assignments

The grading is based on 2 take-home exams that will be distributed to the students during the course.

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. 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 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

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.

modeling and control of hybrid systems

lecturers

Prof.dr.ir. B. De Schutter, Delft University of Technology
Prof.dr.ir. W.P.M.H. Heemels, Eindhoven University of Technology

objective

Recent technological innovations have caused a considerable interest in the study of dynamical processes of a mixed continuous and discrete nature. Such processes are called hybrid systems and are characterized by the interaction of time-continuous models (governed by differential or difference equations) on the one hand, and logic rules and discrete-event systems (described by, e.g., automata, finite state machines, etc.) on the other. A hybrid system also arises in practice when continuous physical processes are controlled via embedded software that intrinsically has a finite number of states only (e.g., on/off control).
This course will offer a brief overview of the field of hybrid systems ranging from modeling, over analysis and simulation, to verification and control. We will particularly focus on modeling, analysis, and control of tractable classes of hybrid systems.

contents

1. General introduction. Examples of hybrid systems & motivation. Modeling frameworks (automata, hybrid automata, piecewise-affine systems, complementarity systems, mixed logic dynamical systems, ...);
2. Properties and analysis of hybrid systems (well-posedness, Zeno behavior, stability, liveness, safety, ...);
3. Control of hybrid systems (switching controllers, model predictive control, ...);
4. Control of hybrid systems (continued). Verification. Tools.

course materials

B. De Schutter and W.P.M.H. Heemels, "Modeling and Control of Hybrid Systems", Lecture Notes for the DISC Course. Revised edition 2014. These lecture notes will be made available electronically.

prerequisites

Basic undergraduate courses in systems and control.
Basic programming skills (Matlab).

homework assignments

Three homework assignments will be handed out. The assignments will be graded and the average grade will be the final grade for this course.

course website

http://www.dcsc.tudelft.nl/~disc_hs/course/

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

course materials

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 thehomework 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

distributed parameter systems

lecturers

Prof. dr. H.J. Zwart, University of Twente
Dr. A.M.C. Ran, Free University Amsterdam

objective

Modeling of dynamical systems with a spatial component leads to lumped parameter systems, when the spatial component may be denied, and to distributed parameter systems otherwise. The mathematical model of distributed parameter systems will be a partial differential equation. Examples of dynamical systems with a spatial component are, among others, temperature distribution of metal slabs or plates, and the vibration of aircraft wings.

This course provides an introduction to linear distributed parameter systems. We will study the state space formulation of these systems. Special attention will be paid to the class of port-Hamiltonian systems in which the norm of the state is given by the energy (Hamiltonian) of the system. This fact enables us to show relatively easy the existence and stability of solutions. Further, it is possible to determine which boundary variables are suitable as inputs and outputs, and how the system can be stabilized via the boundary. For the stabilization we look at static, dynamic and non-linear dynamic controllers.
At the end of the course the students should be able to model distributed parameter systems as distributed parameter system, and should be able to apply known concepts from system and control theory like stability, stabilizability and transfer functions to these systems.

contents

1. Distributed parameter system and its mathematical formulation.
2. Mathematical background.
3. Existence of unique solutions.
4. Control/observation at the boundary
5. Transfer functions
6. Stability and stabilizability.
7. Semi-linear systems
8. Dynamic boundary stabilization

lecture notes

Lecture notes are under preparation and will be distributed during the presentations of the course.

prerequisites

Basic undergraduate courses in systems and control.

homework assignments

Four homework assignments will be given during the course lectures. The assignments will be graded and the average grade will be the final grade for the course.

automatic verification and synthesis of complex systems

lecturers

Dr. ir. M. Mazo Jr., Delft University of Technology
Dr. A. Abate, University of Oxford

objective

The use of concepts, techniques, and algorithms originated in the literature on Formal Verification in the Computer Sciences has recently become common and successful within the Systems & Control community. Known formal notions that are fundamental in Computer Science, such as that of symbolic (finite) abstraction, or that of bisimulation relation, are increasing their presence in the study of continuous dynamical and control systems, thanks to their ability to provide formal and algorithmic solutions to complex analysis and controller synthesis problems. Their use is particularly cogent in the area of Cyber-Physical Systems, where physical models share dynamics, control, and computational aspects. The use of techniques from formal methods thus targets two goals: formal analysis and synthesis, as well as computational solutions.

This course aims are providing an introduction to the area, and to lead the student to appreciate the most modern developments in this research field. The course is inter- disciplinary and could likewise target a systems and control audience, as well as a computer science audience open to learn about dynamical and control models and problems.

More specifically, the goals of the course are:
- To establish a sufficiently strong common ground to enable entering the inter- disciplinary research field of Verification and Control of complex systems employing symbolic methods.
- To illustrate the relevance of these new techniques in the design of embedded controllers, and in the analysis of safety requirements.
- To provide the students with a new set of tools to solve complex practical control problems, relying on recent theoretical achievements as well as modern software tools. By taking the course, the student will learn:
- To model a cyber-physical system via complex models such as hybrid or networked models, with possible non-determinism and stochasticity.
- To appreciate the power of formal verification and controller synthesis approaches, based on notions of equivalence or abstraction, and relying on computational symbolic algorithms.
- To verify a complex dynamical model over rich specifications expressed in known logical frameworks or computational structures.
- To synthesise digital controllers over physical models by the aforementioned techniques and software.
- To run dedicated modern software tools in the area, inclusive abstraction tools (see below) and model checkers in the industrial practice.

contents

The course is structured into four lectures. The content of the four sessions cover the following topics:
(1) Introduction to problems of Verification and Control in a generalised setting. Models – notion of general transition systems (as special examples, discussions of finite-state machines, ODEs, hybrid systems). Determinism and non-determinism. Properties – modal and temporal logics, specifications, automata (examples in safety, liveness, reachability). Automatic verification of specifications over systems: reachability, safety, model checking.
(2) Shortcomings of classical analysis of complex models – the need for formal abstractions. Model abstractions – notions of equivalences and preorders: bisimulation and simulation relations. Approximate notions of abstractions. Metrics over models. Refinements.
(3) Non-determinism vs structural uncertainty: motivating probabilistic models – from Markov Chains to Stochastic Hybrid Systems. Stochastic counterparts of the notions and relations discussed in session 1 and 2.
(4) Overview of Software tools for abstraction, verification, and controller synthesis. Verification via reachability. Verification via model checking. Case studies.
Presentation of the final course assignment.

course material

- P. Tabuada, Verification and Control of Hybrid Systems, Springer, 2009 (Selected chapters, available on line under institutional subscription)
- C.Baier and J-P. Katoen, Principles of Model Checking, MIT Press, 2008 (Selected chapters)
- Lectures notes, handouts, and homework material, to be distributed during the course.
- Software for formal verification and synthesis:
  – PESSOA, https://sites.google.com/a/cyphylab.ee.ucla.edu/pessoa/
  – FAUST2, http://sourceforge.net/projects/faust2/

prerequisites

Undergraduate courses on systems and control over the state space. Familiarity with MATLAB and, in general, basic programming notions would be helpful for the final assignment of the course. Mathematical maturity, as well as a genuine interest to bridge between two scientific areas (systems & control, and formal methods).

homework assignments

There would be two homework assignments, each of which would amount to 15% of the final grade and will be aligned with the content of the first three sessions. The remaining 70% would come from a final computer-based assignment, in which the students synthesize or verify a simple control system with existing software packages discussed in the fourth session.

unit disc

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 (note this list is incomplete and will be extended in due time; please check the DISC site for the most recent information):

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