M.Sc. in Systems and Control – Integration Project (SC42035)

Course Information for Academic Year 2017/2018

General Information

The Integration Project is a compulsory course for students following the M.Sc. program 'Systems and Control.' It is taught by the staff of the Faculty of 3mE, Delft University of Technology.

Course year	first year of the M.Sc. program
Term	fourth quarter (April – June)
ECTS credits	5 (140 hours)
Prerequisites	Control Theory (SC42015) Filtering and Identification (SC42025) Modeling and Nonlinear Syst. Th. (SC42060)
Lectures	introductory lecture on Monday April 23, 2018, 8:45 – 10:30, room D
Lab sessions[1]	throughout the fourth quarter in the labs of DCSC, Mekelweg 2
Responsible lecturer	Dr.-Ing. Jens Kober Cognitive Robotics tel: +31-15-27 85150 / 86841 (secr.) email: j.kober@tudelft.nl
Lecturers	Prof.dr. Robert Babuska, 85117 email: r.babuska@tudelft.nl ir. Sander Bregman, 87359 email: s.c.bregman@tudelft.nl
Assistants	Nikolaos Moustakis, M.Sc. email: n.moustakis@tudelft.nl Mr. Alexandre Melo Pacheco email: a.melopacheco@student.tudelft.nl Mr. Jose Libardo Navia Vela email: j.l.naviavela@student.tudelft.nl
Final grade	written report 40%, discussion of the report 40%, technical presentation 20% evaluation of the laboratory sessions
Web page	http://www.dcsc.tudelft.nl/˜sc42035

[1]Students will plan the lab sessions themselves. Given the study load of 140 hours and the duration of the quarter of max 9 weeks, please, plan to spend on average 15-16 hours a week on the course. It is suggested to spend approximately 6 hours a week in the lab and devote the remaining time to preparation and reporting.

Course Subject

The goal of this course is to integrate and apply the theoretical knowledge gained in the courses 'Control Theory' (SC42015), 'Filtering and Identification' (SC42025), and 'Modeling and Nonlinear Systems Theory' (SC42060), which are compulsory within the M.Sc. program 'Systems and Control.' The concepts and tools to be used include mechanistic modeling (based on principles like mass balances, Lagrange equations, etc.), filtering and estimation (e.g., Kalman filtering), linear control design and performance analysis, system identification in open and closed loop. It is assumed that students already know these concepts or are able to look them up in the literature. No theoretical lectures are given in this course.

The course is based on practical laboratory sessions, in which students gain hands-on experience with the application of control theory to real-world systems. MATLAB and Simulink are used as the primary software environment for the design, analysis and real-time implementation of the algorithms. Students work in groups of two in the lab, with a setup of their choice: inverted pendulum, 'helicopter' model, inverted wedge, rotational double pendulum, overhead crane, flexible link, magnetic levitation, Qube servo & pendulum, magnatic manipulation, ball & beam, smart beam, and linear actuator with flexible load.

A basic description of each setup is provided. However, the derivation of a mathematical model and the tuning or estimation of its parameters are a part of the assignment. Likewise, a general statement of the control objective is given, but it has to be refined by the students in the initial phase of the project. The results will be summarized in a written report which will be discussed with the course lecturers. The grade is determined on the basis of the report, a technical presentation, and a discussion of the report (i.e., there is no written exam).

Keywords: Modeling, system identification, filtering and state estimation, control design, discrete-time systems, sampled-data controllers, MATLAB and Simulink, control lab, mechatronic systems.

Instructional Objectives

After successfully completing the course, you should be able to:

- apply system and control theory to medium-complexity lab-scale and real-world processes,
- extrapolate the skills and knowledge gained to other, more complex problems,
- effectively use MATLAB and Simulink for analysis, control design and related tasks,
- document the design process and its results in a high-standard technical report and give a presentation.

Control Design Methods

The following methods and techniques will be applied to the lab setups:

- Mechanistic modeling based on Lagrange equations and mass balances.
- Implementation of a (nonlinear) mathematical model in Simulink.
- System identification and/or parameter estimation in order to calibrate the model, such that it can be used for model based control design and realistic simulations.
- Linearization and discretization of the model.
- Design of a linear Kalman filter (or a deterministic observer) for state estimation.

- Linear control design and performance analysis – apply at least two different methods, evaluate and compare their performance.
- System identification in closed loop – verify and possibly improve the accuracy of the model. Within this project, closed-loop identification is optional, though recommended.

These are 'minimal' requirements; it is, of course, always possible to use nonlinear methods. In such as case, the results obtained with linear techniques must serve as a baseline solution for comparisons.

Course Material

The material includes the lecture notes, books and transparencies used in the courses 'Control Theory' (SC42015), 'Filtering and Identification' (SC42025), and 'Modeling and Nonlinear Systems Theory' (SC42060). Furthermore, students are encouraged to search the library and on-line resources for publications on the lab setups (or their variants used elsewhere), the control methods applicable to these setups, other control design problems and examples, MATLAB (on-line) manuals, etc.

The course Web page contains a number of useful links, such as the Delft University library site (library.tudelft.nl), IEEE Xplore (ieeexplore.ieee.org), Elsevier Science Direct (sciencedirect.com), IFAC (www.ifac-control.org), the Mathworks (mathworks.com), etc.

Course Organization

The main ingredients of this course are practical laboratory sessions, self-study and preparation, discussions with the lecturers and reporting.

Lectures. There is one introductory lecture (2 hours) in the first week of the quarter. The purpose of the lecture is to give information about this course, form groups of two students for the lab sessions and assign lab setups to the groups. There may also be guest lectures, these will be announced at due time.

Laboratory sessions are the most essential part of this course. The purpose is to apply your knowledge of theory to lab setups and to gain hands-on experience with the control of a real physical process. In the lab sessions, students work independently. If help or guidance is needed, please, contact the assistant or the lecturers. To prepare the lab sessions the following two steps must be followed:

1. Choose your partner (the work is done in groups of two) and the laboratory setup. These choices should be made during the introductory lecture.
2. Prepare a schedule for the lab sessions within the quarter. It may happen that one setup is shared by two or three groups of students; proper planning is therefore necessary. Plan to spend on average 16-17 hours a week on the course. It is suggested that approximately 6 hours are spent in the lab and the remaining time is devoted to preparation and reporting.

Discussions with the lecturers. At least two intermediate and one final discussion with the lecturers will take place during the course period. Students themselves are responsible for planning and preparation of these discussions and for making appointments with the lecturers. The schedule is as follows:

1. First intermediate discussion (first half of the quarter). Purpose: present a detailed plan of what are going to do during the whole course period, discuss your results in modeling and system identification, and the control design methods you deem appropriate for 'your' setup.
2. Second intermediate discussion (second half of the quarter). Purpose: discuss the results achieved so far, problems encountered and your plan for the rest of the course.
3. Final discussion (end of the quarter). Purpose: evaluation of results, presented in a written report (to be delivered in advance, see below).

In addition, each group must be present in the lab every week during the scheduled time slot for a brief, ad hoc progress discussion with the lecturer or assistant.

Report. The results must be presented in a written report, which will serve as a basis for the final evaluation. The maximum number of pages is 30. Deadline: Friday June 22, 2018 by 16:00.

Final grade. There is no written exam. The grade will be determined on the basis of your report (one report per group), the final discussion, and the presentation. The main criteria for the report are completeness and clarity. On the basis of the report, any educated reader should be able to reproduce your results with the laboratory setup. All choices made (such as the selection of the sampling period, design parameters, etc.) must be properly motivated. Evaluate critically the results obtained. Do not include theory that can be found elsewhere. Deliver the MATLAB / Simulink files you developed per e-mail. The report must be delivered on paper (2 copies in the mailbox of Jens Kober, 3mE block E, ground floor) and electronically, by e-mail to j.kober@tudelft.nl and r.babuska@tudelft.nl.

Matlab and Simulink. One of the objectives of the course is to learn to use MATLAB, Simulink and the Control Systems Toolbox for computer-assisted design, analysis and implementation of control systems. It is important that you can use this software for your home preparation for the lab sessions. There are several possibilities:

- At your home PC: you may download MATLAB through Brightspace and install it on your PC.
- In the computer rooms 3mE and possibly other faculties.
- At DCSC: please, discuss with the lecturer, availability may be restricted due to other activities.

The first option is probably the most convenient one.

Questions? You are encouraged to ask questions and discuss problems during the entire course period. Please, make an appointment with one of the lecturers or assistants. Do not postpone your questions; as the end of the quarter is usually busier, the availability of the staff may be limited.

Feedback is important, not only in control theory. We very much appreciate comments, suggestions and criticism you may have on any aspect of this course. Please, feel free to approach the lecturers and the assistants with your suggestions.