Technische Universiteit Eindhoven University of Technology

Department of

Electrical Engineering

August 2019

Study Guide 5ESD0
Control Systems

Department of Electrical Engineering

Control Systems Group (CS)

Prof.dr.ir. Paul Van den Hof

Dr.ir. S. Haesaert

Ing. Will Hendrix

Version: 26 August 2019

Technische Universiteit
Eindhoven
University of Technology

Content

1. Introduction

This study guide explains the goals and procedures around the BSc course “Control Systems” / 5ESD0, which is a compulsory course in the 3rd year of the Bachelor College for students in the Electrical Engineering and in the Automotive Systems programs. The study guide serves in addition to the regular information that is available through www.canvas.tue.nl. Most up-to-date information is always available on CANVAS.

2. Course setup

2.1 General information

Course title	Control Systems
Course code:	5ESD0
Quartile:	1
Program::	BSc College EE (year 3), compulsory BSc College AU (year 3), compulsory
Type of education:	10 sessions of lectures combined with exercise/instructions sessions (10 x 4 hours); two lab projects (12 hours), performed by groups of 2 students.
ECTS credits:	5
Course subject:	Control systems are omnipresent in everyday use of technology. The basic principles of control of linear dynamic systems are explored, and design methods are treated for designing control systems to handle design specifications in terms of speed (bandwidth), stability and robustness under presence of disturbances and sensor noises. Achievements and limitations are being addressed and the theory is complemented with design assignments on laboratory setups.
Lecturers:	prof.dr.ir. Paul Van den Hof (responsible lecturer) dr.ir. Sofie Haesaert (co-lecturer) ing. Will Hendrix (lab projects) ir. Giuseppe Belgioioso (head teaching assistant) ir. Clarissa Bosman (teaching assistant - Instructions) ir. Zuan Khalik (teaching assistant - Instructions) ir. Khartik Ramaswamy (teaching assistant - lab projects) ir. Shengling Shi (teaching assistant - lab projects)
Course material:	There is a compulsory book: G.F. Franklin, J.D. Powell and A. Emami-Naeini, "*Feedback Control of Dynamic Systems*", 7th Edition, Pearson, 2015, available through the study association THOR. The same book has also been used for the 1st year's Systems course (5ESB0). Additionally the slides used in the lectures will be made available through CANVAS. Additional material: K.J. Åström and R.M. Murray, "*Feedback Systems – An Introduction for Scientists and Engineers",* Princeton University Press, Princeton, NJ, USA, 2008. For personal (studying) purposes the book is available online via the webpage by Prof. R.M. Murray (California Institute of Technology, USA).
Group:	Control Systems (CS), Department of Electrical Engineering.
Secretariat:	secretariaat.cs@tue.nl, FLUX 5.132, tel: 040 2472300.

2.2 Learning objectives and content

After completing this course the student will be able to:

- Understand how closed-loop properties of systems can be influenced by adjusting the open-loop frequency response of the loop transfer
- Design single-loop stabilizing feedback controllers on the basis of available frequency responses
- Design single-loop feedback controllers with frequency-domain loop shaping techniques
- Analyze and synthesize feedback controllers and evaluate their performance using Matlab tools
- Understand the conflicting requirements that can be imposed on a control system in terms of bandwidth, tracking performance, disturbance rejection and sensitivity to sensor noise
- Interpret specifications on gain margin and phase margin
- Understand the design limitations that are imposed by the Bode sensitivity integral
- Understand performance limitations of feedback control systems, imposed by system properties such as time delays, non-minimum phase behaviour, instability
- Design pole-placement controllers in state space form, while guaranteeing reference tracking properties
- Assess whether state space systems are controllable / observable.
- Design simple observers for state space systems
- Understand the limitations of sampled-data (digital) control, and design digital control systems

The course has the following core subjects:

- Stability analysis for closed-loop systems
- From frequency response models to closed-loop properties
- Nyquist criterion for stability; stability margins
- The frequency response design method (loop shaping)
- Lead and lag compensators and their relation with PI and PD control
- Sensitivity function and the Bode sensitivity integral
- Design and performance limitations of control
- State space design
- Digital control

2.3 Position in the curriculum

Prior knowledge:	EE-students: Modelling (0LAB0), Signals I (5ESA0), Systems (5ESB0) AU-students: Modelling (0LAB0), Signals+Math (2DE30), Systems (5ESB0)
Follow-up courses:	MSc courses in the field of Systems and Control

2.4 Education format and evaluation

For this course there are 10 hours/week planned in the schedule of Q1.

There are 10 lectures and 10 exercise/instructions of 2 hours each, according to the schedule included in Section 2.5. For the appropriate lecture rooms, see the information in MyTimeTable. The lectures are typically in AUD 6.

Sets of written exercises are made available for each of these sessions through CANVAS. These exercises are for training only and are not handed in/graded.

There are two lab assignments that are being executed in groups of up to two students. The following lab hours are planned for:

Lab 1 assignment: 2 times 2 hours lab access

Lab 2 assignment: 4 times 2 hours lab access

The two lab assignments are each completed by a written report and in some cases oral discussion with one of the lab supervisors. The grades for the lab projects count for 20% in the final grade of the course and depend on the lab preparation and execution.

The course is completed by a written exam.

- The laboratory projects count for 20% of the final grade.
- The grade for the written exam counts for 80% in the final grade.
- To pass the course, the minimum grade for the written exam is 5.

There is a written exam for the course at the end of Q1 (November) and a resit exam in January. Registration for the written exams is compulsory.

Lab grades obtained in Q1 of 2019-2020 will remain valid for the exam session of November 2019 and the resit exam in January 2020.

Written exam

There will be written exam at the end of Q2. It is allowed to use one **hand-written A4 page of notes/formulas (two sides, no reduced-sized copied versions)**. It is also allowed to use a non-programmable calculator. The written exam is scheduled for **Wednesday 6 November 2019**, 13:30 – 16:30**.** There will be a resit exam on **Wednesday 29 January 2020**, 18:00 – 21:00.

2.5 Course schedule

5ESD0 Control Systems - Tentative Schedule 2019/2020

Version: 26-08-2019

Day	Slot	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	
Mon		02/Sep	09/Sep	16/Sep	23/Sep	30/Sep	07/Oct	14/Oct	21/Oct	28/Oct
	1, 2					Reserve slots	Group A (3)	Reserve slots	Group A (5)	
	3, 4					Reserve slots	Group A (4)	Reserve slots	Group A (6)	
	5, 6, 7, 8									
Tue		03/Sep	10/Sep	17/Sep	24/Sep	01/Oct	08/Oct	15/Oct	22/Oct	29/Oct
	1, 2	LECT 1	LECT 3	LECT 5	Group A (2)	LECT 6	LECT 8	LECT 10	Group D (5)	
	3, 4	LECT 2	INSTR 3	INSTR 5	Group B (2)	INSTR 6	INSTR 8	Guest lecture	Group D (6)	
	5, 6, 7, 8									
Wed		04/Sep	11/Sep	18/Sep	25/Sep	02/Oct	09/Oct	16/Oct	23/Oct	30/Oct
	1, 2					Reserve slots	Group B (3)	Group B (5)	Reserve slots	
	3, 4					Reserve slots	Group B (4)	Group B (6)	Reserve slots	
	5, 6									
	7, 8			Deadline Lab prep.1						
Thu	1	05/Sep	12/Sep	19/Sep	26/Sep	03/Oct	10/Oct	17/Oct	24/Oct	31/Oct
	2, 3			Group C (1)	Group C (2)		Group C (3)	Group D (3)	Group C (5)	
	4, 5			Group D (1)	Group D (2)		Group C (4)	Group D (4)	Group C (6)	
	6, 7, 8									
Fri		06/Sep	13/Sep	20/Sep	27/Sep	04/Oct	11/Oct	18/Oct	25/Oct	01/Nov
	1									
	2, 3				education free					
	4					deadline lab 1				deadline lab 2
	5, 6	INSTR 1	LECT 4	Group A (1)		LECT 7	LECT 9	LECT RES	Reserve slots	
	7, 8	INSTR 2	INSTR 4	Group B (1)		INSTR 7	INSTR 9	INSTR 10	Reserve slots	

Lab sessions are in green (lab 1: light green, lab 2: dark green). There are four Lab groups: A-D.

2.6 Course subjects per week

The table below indicates the course subjects for each lecture, including the related material in the book. This is a tentative schedule and can be adapted during the course.

	Course Subjects per Lecture	
Lecture	**Subject**	**Book material**
1	Introduction to control of dynamic systems; refresher on systems concepts	
2	Root locus	FP 5.1, 5.2.1
3	Frequency responses; Bode plot techniques; closed-loop steady state errors and neutral stabiity	FP 6.1, 6.2
4	Frequency response design methods – loop shaping, lead and lag compensation and relation with PI, PD and PID.	FP 6.7
5	Closed-loop Stability, Nyquist stability criterion and the Nyquist plot. Stability margins and Bode's Gain-Phase relationship	FP 6.3 – 6.6
6	Design trade-offs and the role of sensitivity functions	FP 6.7.6, 6.7.7, 6.7.8
7	Fundamental limitations and feed-forward control	AM 11.2, 11.5
8	State-space design: concepts and state-feedback	FP 7
9	Guest lecture: control for high performance lithographic machines	
10	Digital control	FP 8

FP = G.F. Franklin, J.D. Powell and A. Emami-Naeini, "*Feedback Control of Dynamic Systems*", 7th Edition, Addison-Wesley Publishing Company.

AM = K.J. Åström and R.M. Murray, "*Feedback Systems – An Introduction for Scientists and Engineers*", Princeton University Press.

2.7 Lab projects (LAB)

Included in this course are two laboratory projects that are being executed by teams of two students each. Each assignment includes a couple of sessions of access to the experimental platforms. These hours are scheduled in the indicated LAB blocks in the previous schedule.

The location of the Lab sessions will be the rooms FLUX 10.072 and FLUX 10.070.

Registering for the labs

Students can register for the Lab hours in one of the 4 groups that are listed on CANVAS. These 4 groups have lab session scheduled as follows:

- Group A: Friday afternoon (20 sept), Tuesday morning (24 sept), Monday mornings (7,21 oct)
- Group B: Friday afternoon (20 sept), Tuesday morning (24 sept), Wednesday mornings (9,16 oct)
- Group C: Thursday mornings (19, 26 sept, 10,24 oct)
- Group D: Thursday mornings (19, 26 sept, 17 oct),Tuesday morning (23 oct)

Please register yourself in a group that allows you to be available for the labs for the entire duration of the course, you can only be registered in 1 group!
For the LABs, students must **register in CANVAS ultimately Friday September 6th**, but it is recommended to register as soon as possible

Lab schedule and procedure

Two separate lab assignments will be given during the lab sessions. The first assignment (**Lab 1**) deals with control design for a linear SISO system, i.e., a mass-spring-damper-mass system, which was previously studied in the lab sessions of the Systems course. The second assignment (**Lab 2**) deals with control of a non-linear system, i.e., a magnetically levitated ball. The exact assignments will be provided during the first week of the course, and will be available on the CANVAS website in the “Lab 1-2 files” folders and via the lab module.

Lab 1 is graded based on the lab preparation and execution. Support for making the lab preparation is provided in instruction sessions 4 and 5. The **lab preparation** has to be submitted to the Matlab grader (grader.mathworks.com) by **18 September 2019**. The report of lab 1 has to be submitted by **4 October 2019.**

Students without a passing grade for the lab preparation cannot start the experiments of lab 1!

Lab 2 is graded based on the lab preparation and execution. Lab preparation includes watching the lab videos (see canvas) and reading the lab assignment. A part of the assignment needs to be executed outside of the lab. The report of lab 2 has to be submitted by **1 November 2019.**

Lab 1	**Lab 2**
Lab preparation: Design filter and Controller • Solve Matlab graded assignments • Support in instruction session 4-5 • deadline 18 September 2019	Lab preparation: • Watch lab video • Read assignments
Lab Session 1: 2 Hours lab experiments	Lab Session 1: 4 Hours lab experiments
Report deadline 4 October 2019	Report deadline 1 November 2019

Assignments and preparation instructions of the Lab reports

Each group of students (up to 2 students per group) must submit a PDF file with the lab report per assignment. Each report should be no more than 8 pages long, excluding the title page. The format of the report will be available on the CANVAS website under the “Lab 1-2 files” folders. Submission of the assignment should be done through CANVAS.

Deadlines

- 6 September 2019 – Register for the labs through Canvas
- 18 September 2019 – Deadline for lab 1 preparation via the Matlab grader.
- 4 October 2019 – Submission deadline for the reports on the Lab assignment 1.
- 1 November 2019 – Submission deadline for the reports on the Lab assignment 2.
  It is strongly advised to submit the report in advance if it is completed earlier.

Examination

The examination of the laboratory work will typically be based on the report, but students may be invited for oral examination that will include a discussion based on the report and the performance of the developed controller.

2.8 Questions and feedback

The team of lecturers and teaching assistants is available during and after the lecturing/exercise hours for individual questions, comments and feedback. Comments and feedback can also be provided through the CANVAS forum and e-mail. Appointments with the lecturers can be made through the group secretariat (secretariaat.cs@tue.nl).

If you would like to check the detailed grading of your written exam, contact the head teaching assistant, or the co-lecturer for an appointment.