*Course Syllabus*

# ELEC-E8101: Digital and Optimal Control

**Abstract**

This document describes the course ELEC-E8101 Digital and Optimal Control, 5 credits, Periods I and II of Academic year 2021/2022. Any changes to the information in this document will be announced on the course's website, which is found at MyCourses.

## Contents

# 1 General Information

### Literature

[1] The main reference book for this course is *"Computer-Controlled Systems: Theory and Design"* by Karl J. Åström and Björn Wittenmark. There are plenty of copies of the book available in the university's libraries.

[2] *"Dynamic Programming and Optimal Control"* by Dimitri Bertsekas

[3] *"Optimal Control Theory: An Introduction"* by Donald E. Kirk

### Lecturers

Mohammadreza Dostmohammadian (Reza) - Themistoklis Charalambous,
Zoom ID (Office hours): https://aalto.zoom.us/j/8458656945 (same as lectures)
Meeting ID: 845 865 6945, **Passcode: EE8101**
Room: I308b, I-wing, Otakaari 5.
Office hours: Fridays, 17:00-19:00.

### Teaching assistants

*Exercise sessions:*
TBD
Office hours: Wednesdays 14:00-16:00.

*Project:*
Pyry Veijalainen,
Zoom ID (Office hours): https://aalto.zoom.us/j/66560678359
Room: Open Innovation House (OIH), room B204.
Office hours: Tuesdays 10:00-12:00 and Thursdays 10:00-12:00

*Homework:*
Amr Alkhashab

### Additional material

Additional material (e.g., material on pre-requisites, extra exercises, scientific papers) will be made available to download from MyCourses.

### Exercise Sessions

There are 11 exercise sessions in the course (9 exercise sessions and a tutorial); details are found in Section 6.

### Homework

There are 4 homework assignments in the course; details are found in Section 7.

### Quizzes

There are 10 quizzes in the course; details are found in Section 8.

### Project

During the course there will be laboratory work on a small-scale Segway; details are found in Section 9.

### Written exam

There will be a written exam at the end of the course; details are found in Section 10.

# 2 Prerequisites

- Basic course in Automation and Control Engineering; e.g., the course ELEC-C8201:Control and Automation. If you have not taken any course before, it is recommended to take ELEC-C8201:Control and Automation in the Spring and then attend this course next year.
- Programming skills in Matlab/Simulink.

## 3 Aim and Learning Outcomes

The main aim of the course is to help students acquire in-depth knowledge of digital control, the design of digital feedback control systems, and their use in various engineering applications, ranging from control to medicine and biology.

After completing the course the student will:

- understand the principles of discrete-time modeling and computer control;
- understand the common ideas and differences between analog and digital control;
- be able design, simulate and implement discrete-time controllers (for example discretized PID or state feedback controllers);
- understand the Principle of Optimality;
- understand the ideas behind optimal controllers, specifically LQ control;
- can design and implement LQ controllers;
- understands the basics of stochastic control theory and can implement the Kalman filter.

## 4 Tentative Weekly Plan

A tentative week plan follows below. Changes to the plan will be posted on MyCourses. All lectures and exercise sessions, apart from Lecture 3, will take place online in Zoom (till further notice by Aalto officials on COVID situation). Lecture 3 will take place in TU2, TUAS Building, Maarintie 8.

| # | Day, Time | Activity | Content | Comments |
|---|---|---|---|---|
| 37 | Sep 17, 14:15-16:00 | Lecture 1 | 1. Introduction & Laplace transforms | |
| 38 | Sep 24, 14:15-16:00 | Lecture 2 | 2. Analysis of discrete-time systems using $z$-transforms | |
| 39 | Sep 29, 14:15-16:00<br>Oct 1, 14:15-16:00 | Tutorial<br>Tutorial | Laplace transforms & partial fractions<br>Introduction to the group project:<br>*Control of a balancing robot* | |
| 40 | Oct 6, 14:15-16:00<br>Oct 8, 14:15-16:00 | Exercise 1<br>Lecture 3 | Analysis of discrete-time systems using $z$-transforms<br>3. Discretization | <br>Quiz 1 |
| 41 | Oct 13, 14:15-16:00<br>Oct 15, 14:15-16:00 | Exercise 2<br>Lecture 4 | Discretization<br>4. Discrete PID Controllers | <br>Quiz 2 |
| 42 | Oct 20, 14:15-16:00<br>Oct 22, 14:15-16:00 | Exercise 3<br>Lecture 5 | Discrete PID Controllers<br>5. State-space representation | <br>Quiz 3 |
| 43 | Evaluation & examination week | | | |
| 44 | Nov 3, 14:15-16:00<br>Nov 5, 14:15-16:00 | Exercise 4<br>Lecture 6 | State-space representation<br>6. Stability of discrete-time systems | <br>Quiz 4 |
| | Nov 10, 23:55 | | | Lab A |
| 45 | Nov 10, 14:15-16:00<br>Nov 12, 14:15-16:00 | Exercise 5<br>Lecture 7 | Stability of discrete-time systems<br>7. Controllability, Reachability, Observability, and Detectability | <br>Quiz 5 |
| 46 | Nov 17, 14:15-16:00<br>Nov 19, 14:15-16:00 | Exercise 6<br>Lecture 8 | Controllability, Reachability, Observability, and Detectability<br>8. Pole-placement design: a state-space approach | <br>Quiz 6 |
| | Nov 24, 23:55 | | | Lab B |
| 47 | Nov 24, 14:15-16:00<br>Nov 26, 14:15-16:00 | Exercise 7<br>Lecture 9 | Pole-placement design: a state-space approach<br>9. Optimal design methods: a state-space approach | <br>Quiz 7 |
| 48 | Dec 1, 14:15-16:00<br>Dec 3, 14:15-16:00 | Exercise 8<br>Lecture 10 | Optimal design methods: a state-space approach<br>10. Stochastic Optimal Control | <br>Quiz 8 |
| 49 | Dec 8, 14:15-16:00 | Exercise 9 | Stochastic Optimal Control, Revision and Q&A | |
| | Dec 8, 23:55 | | | Lab C |
| 50 | Evaluation & examination week | | | |
| | Dec 15, 14:00-17:00 | Final exam | All the material covered during the course | |

## 5 Lectures

The objective with the lectures is to highlight the most important concepts of the course. However, it is not possible to cover all relevant parts in all details.

| # | Activity | Additional Resources/Remarks |
|---|---|---|
| 1 | Lecture Slides 1 | |
| 2 | Lectures Slides 2 | |
| 3 | Lectures Slides 3 | |
| 4 | Lectures Slides 4 | |
| 5 | Lectures Slides 5 | |
| 6 | Lectures Slides 6 | |
| 7 | Lectures Slides 7 | |
| 8 | Lectures Slides 8 | |
| 9 | Lectures Slides 9 | |
| 10 | Lectures Slides 10 | |

## 6 Exercise Sessions

The purpose of the Exercise Sessions is *not* to solve a lot of standard problems at high speed. The purpose is to facilitate learning and understanding of the course material. The ability to solve standard problems does not imply understanding; however, understanding gives problem-solving skills.

It is important that you come prepared to the exercises, i.e., that you have read the relevant material, and perhaps also solved some of the suggested exercise problems.

It is also important that you are active during the exercises. Always try to understand what aspects of control theory the problems are treating. If you cannot see the point with a certain problem, ask the teaching assistant! There is a meaning behind every problem in this course.

A typical Exercise Session will start with a short review of the theory and a motivation why the theory is of use for an engineer. The teaching assistant solves the problems on the board.

## 7 Homework

There will be 4 homeworks (1 every 2 weeks roughly) that you will have to solve and submit your solutions in MyCourses. More details will be given during the course. The purpose of the exercises in the homework is to make you assess whether you have understood the main principles taught during the lectures.

## 8 Quizzes

There will be 8 quizzes during the course, each accounting 0.5 points (4 points in total). Each quiz will be available online in MyCourses 24 hours before the lecture starts (starting from lecture 2 onwards; see *Tentative Weekly Plan* in Section 4) and it will expire 15 minutes before the lecture starts. It will cover material on the previous lecture. The purpose of the quiz is to *i* motivate the students to revise the material of the previous lecture and be prepared for the next, and *(ii)* emphasize some key ideas of the previous lecture.

## 9 Project

To consolidate the theoretical knowledge obtained during the course (and even go beyond), laboratory work is performed on a small-scale balancing robot. The intended learning outcome is *not* just to make the balancing robot to stand. It is to learn how to design control schemes in the real world through using a simple and fun object. In practice, you will go through *some* of the fundamental steps that control engineers usually do in their job.

## 10 Written Exam

The course will be concluded with a 3-hour written exam with four/five problems. An erroneous answer, incomplete or badly motivated solutions give point reductions. As a general rule, bad motivation or errors that relate to fundamental principles of the course will lead to large point deductions. Computational errors that do not lead to unreasonable answers generally give smaller point deductions.

The purpose of all exam problems is to test to what degree the students have reached the aims and objectives (see Section 3 on *Aims and Learning Outcomes*). The course is about understanding, not remembering formulae and/or imitating the solution of the exercise problems. Hence, you are allowed to bring with you the Databook of the course in which you can find most (if not all) of the formulae you need.

**Exam date and venue:** December 15, 14:00-17:00 (probably a home exam).

**Re-take exams:** Location for each exam is announced on the exam day in https://into.aalto.fi/display/enaee/Key+dates. Dates for the exams are:

- Monday, 31 Jan. 2022, 16:30-19:30
- Monday, 9 May 2022, 16:30-19:30

## 11 Final Grades

| Assessment | Points |
|---|---|
| **Homework:** 4 homework sheets - 4p per homework | 16 |
| **Quiz:** 8 quizzes (online available 24h before the lecture) - 0.5p per quiz | 4 |
| **Project:** 3 lab reports (Lab A: 10p, Lab B: 10p and Lab C: 10p) | 30 |
| **Exam:** 3-hour exam on December 15, 14:00-17:00 | 50 |
| **Feedback:** At the end of the course, the university asks for your feedback - *bonus* points to those who provide feedback | 3 |
| **Total** | 103 |

The sum of all scores will decide the grade according to the following table:

| **Total score** | 0-39 | 40-49 | 50-59 | 60-69 | 70-84 | $\geq 85$ |
|---|---|---|---|---|---|---|
| **Grade** | Fail | 1 | 2 | 3 | 4 | 5 |