ES4F0-15 Advanced Control Systems

21/22

Department
: School of Engineering

Level
: Undergraduate Level 4

Module leader
: Vishwesh Kulkarni

Credit value
: 15

Module duration
: 10 weeks

Assessment
: 60% coursework, 40% exam

Study location
: University of Warwick main campus, Coventry

Description

Introductory description

ES4F0-15 Advanced Control Systems

[Module web page]

Module aims

The module objective is to teach various methods of synthesizing control systems for real-world complex dynamic systems such that the desired end user objectives are met satisfactorily.

- The dynamic systems considered in this course are real-world systems that can be represented through systems of ordinary differential equations.
- The complexities include large system dimensions (leading to computational challenges), nonlinearities, and time-delays.
- Techniques to test whether the end user objectives are feasible will be taught first and then the techniques for synthesizing requisite controllers will be introduced.
- To ensure that the students understand how to apply the concepts and techniques for real-world applications, the module includes a case study project on synthesizing controller for a process control and a detailed case study involving theoretical questions and a programming assignment.

In this context, the module aims to first introduce mathematical paradigms so that the task of meeting the end-user objectives can be posed as a constrained optimization problem.

- Here, the basics of state-space control, linear programming, and LMI programming will be introduced.

The module then aims to cover some landmark results on the infeasibility of design objectives (e.g., the waterbed theory, limitations due to RHP poles, limitations due to time delays). The module then aims to teach algorithms to check the feasibility of the performance objectives.

In the final 5 weeks, the module aims to cover the salient features of different computational methods, along with associated software programming, of synthesizing a controller (PID controller, H-infinity controller, and L1 adaptive controller) whose robustness properties can be specified a priori by the end user.

Outline syllabus

This is an indicative module outline only to give an indication of the sort of topics that may be covered. Actual sessions held may differ.

Introduction to dynamical systems, review of linear algebra. Least squares optimization for linear systems ODE’s to state-space models, Transient and steady-state response in state-space representations, Controllability and observability, -state feedback controllers, Ackerman’s formula, Input-output stability, introduction to multiplier theory, Stability analysis: effect of time-delay, nonlinearities, and uncertainties, Techniques to characterize robust performance, Sensitivity, complementary sensitivity, and waterbed effect, Bode sensitivity integral, KYP Lemma, Multiplier theoretic characterization of commonly encountered nonlinearities, Multipliers theoretic characterization of time-delays, PID controllers, Introduction to optimal controllers, Introduction to H-infinity control, Introduction to L1 adaptive control, Linear programming and Nonlinear programming algorithms for synthesizing controllers introduced.

The lectures will illustrate the concepts and techniques through several examples including a project and a programming assignment so that the students well understand how those are applied in the context of real-world applications; the students will be given the freedom to choose the applications of their own interest.

Learning outcomes

By the end of the module, students should be able to:

- Given a dynamic system expressed using ordinary differential equations, check whether the end user objectives are feasible or not.
- Pose the controller synthesis problem as a constrained optimization problem using state space representation (note: here, the controller can be PID or optimal or H-infinity or L1 adaptive).
- Use linear and nonlinear programming to solve this problem, and write the associated software code.

Indicative reading list

1. Skogestad and I. Postlethwaite. Multivariable Feedback Control: Analysis and Design (2nd Edition), Wiley Interscience, 2005. ISBN: 9780-4700-11683.
2. G. Franklin, J. Powell, and A. Emami-Naeini. Feedback Control of Dynamic Systems (7th Edition), Pearson, 2014. ISBN: 9781-2920-68909.
3. Stormy Attaway. MATLAB (3rd Edition), Butterworth-Heinemann, 2013. ISBN: 9780-1240-58767.
4. D. Seborg, T. Edgar, D. Mellichamp, and F. Doyle. Process Dynamics and Control (3rd Edition), Wiley, 2011. ISBN: 9780-4706-46106.
5. D. Luenberger and Y. Ye. Linear and Nonlinear Programming (4th Edition). Springer-Verlag, 2016. ISBN: 9783-3191-8841-6e.

View reading list on Talis Aspire

Interdisciplinary

The module is suitable for MSc/MEng students from several disciplines: Systems Engineering, Biomedical Engineering, Mechanical Engineering, Automotive Engineering, Computer Systems Engineering, Power Systems, Renewable Energy.

Subject specific skills

MATLAB programming, linear/nonlinear optimization, stability analysis, robustness analysis, controller design

Transferable skills

MATLAB programming, technical report preparation, PPT preparation, in-class presentation to peers

---

Study

Study time

Type	Required
Lectures	28 sessions of 1 hour (19%)
Seminars	2 sessions of 1 hour (1%)
Project supervision	14 sessions of 1 hour (9%)
Online learning (independent)	10 sessions of 1 hour 30 minutes (10%)
Private study	30 hours (20%)
Total	150 hours

Type	Required
Assessment	61 hours (41%)
Total	150 hours

Private study description

30 hours of lecture-related independent learning -- it is recommended that the student spend 1 hour in private study per 1 hour of lecture. Guidelines for this private/independent study will be provided through the Learn-Reflect-Apply activities on the Moodle page.

Costs

No further costs have been identified for this module.

Assessment

You do not need to pass all assessment components to pass the module.

Students can register for this module without taking any assessment.

Assessment group D2

	Weighting	Study time	Eligible for self-certification
Student Initiated Group Project	30%	30 hours	No

The group project concerns a student initiated engineering case study. The module instructor will set questions testing the student understanding of the breakthrough concepts and techniques in the context of the case study: e.g., compute the poles and zeros of a given system and analyse their impact on the fundamental properties of the given system; conduct a phase-plane analysis of the given system; design a model predictive controller, etc. Nearly 50% of the project work will require the students to write software programmes in MATLAB/SIMULINK/Python. This assignment can be done individually or in a group of 2 or 3 students. The students will present their results in a written format through a report and a ZIP file of well-documented software codes.

Student Initiated Individual Project	30%	30 hours	Yes (extension)

The individual project concerns a student initiated engineering case study. Compared to the Group Project, the student will have more freedom in setting the scope as well as specific tasks for this Project. All the same, as was the case with the Group Project, the module instructor will try to set questions testing the student understanding of the breakthrough concepts and techniques in the context of the case study: e.g., check whether a set of performance objectives is feasible for the given system; conduct stability/robustness analysis for the given system; design a predictor/controller, etc. The students will present their results in a written format through a

	Weighting	Study time	Eligible for self-certification
report and through a 10-minute presentation followed by 10-minute Q&A.			
Online Examination QMP	40%	1 hour	No
~Platforms - QMP			

- Online examination: No Answerbook required
- Students may use a calculator
- Engineering Data Book 8th Edition

Feedback on assessment

- Model solutions to past papers.
- Support through advice and feedback hours.
- Summative mark and written feedback on coursework elements (two case studies).
- Cohort-level feedback on final exam.
- Summative mark and written comments on group presentation.

Past exam papers for ES4F0

Availability

Pre-requisites

To take this module, you must have passed:

- All of
  - ES3C8-15 Systems Modelling and Control
  - ES2A9-15 Engineering Mathematics and Technical Computing

Courses

This module is Optional for:

- RESA-H6P9 Postgraduate Research Wide Bandgap Power Electronics
  - Year 1 of H6P9 Wide Bandgap Power Electronics (EngD)
  - Year 2 of H6P9 Wide Bandgap Power Electronics (EngD)
- Year 1 of TESA-H642 Postgraduate Taught Energy and Power Engineering

This module is Option list A for:

- Year 4 of UESA-H163 MEng Biomedical Systems Engineering
- Year 4 of UESA-H114 MEng Engineering
- Year 4 of UESA-HH31 MEng Systems Engineering
- Year 1 of TESA-H642 Postgraduate Taught Energy and Power Engineering

This module is Option list B for:

- Year 4 of UCSA-G408 Undergraduate Computer Systems Engineering