# ELEC9731

Robust and Linear Control Systems

Term 1, 2022

# Course Overview

## Staff Contact Details

### Convenors

| Name | Email | Availability | Location | Phone |
|---|---|---|---|---|
| Andrey Savkin | a.savkin@unsw.edu.au | TBA | Room 341 | |

## School Contact Information

**Consultations: Lecturer consultation times will be advised during the first lecture. You are welcome to email the tutor or laboratory demonstrator, who can answer your questions on this course and can also provide you with consultation times. ALL email enquiries should be made from your student email address with ELEC/TELExxxx in the subject line; otherwise they will not be answered.**

**Keeping Informed: Announcements may be made during classes, via email (to your student email address) and/or via online learning and teaching platforms – in this course, we will use Moodle https://moodle.telt.unsw.edu.au/login/index.php. Please note that you will be deemed to have received this information, so you should take careful note of all announcements.**

## Student Support Enquiries

For enrolment and progression enquiries please contact Student Services

## Web

Electrical Engineering Homepage

Engineering Student Support Services

Engineering Industrial Training

UNSW Study Abroad and Exchange (for inbound students)

UNSW Future Students

## Phone

(+61 2) 9385 8500 – Nucleus Student Hub

(+61 2) 9385 7661 – Engineering Industrial Training

(+61 2) 9385 3179 – UNSW Study Abroad and UNSW Exchange (for inbound students)

## Email

Engineering Student Support Services – current student enquiries

- e.g. enrolment, progression, clash requests, course issues or program-related queries

Engineering Industrial Training – Industrial training questions

UNSW Study Abroad – study abroad student enquiries (for inbound students)

UNSW Exchange – student exchange enquiries (for inbound students)

UNSW Future Students – potential student enquiries

- e.g. admissions, fees, programs, credit transfer

# Course Details

## Units of Credit 6

## Summary of the Course

Rationale for the study of linear methods. Continuous and discrete LTI systems (tf,zpk and ss), discrete-time approximations. Controllability, canonical forms, pole placement (state feedback design). Observability. Lyapunov stability applied to linear systems. Basic robustness (SISO), sensitivity and complementary sensitivity, classical loop shaping, SISO dynamic controller design using polynomial methods. Robustness (MIMO), singular value decomposition, loop shaping analysis and loop shaping (state feedback). Basic least squares theory as basis for LQR and LQE. The optimal linear regulator, discrete and continuous. Kalman filter and predictor (discrete, continuous). Advanced loop shaping, LTR (continuous time). Advanced robustness, disturbance rejection, H-infinity. Decoupled MIMO controller design. Recursive least squares identification.

## Course Aims

Provide an introduction to multivariable linear system theory and control from both an input/output and a state space point of view. Provide an introduction to Robust Control and Filtering and some aspects of System Identification.

## Course Learning Outcomes

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

| Learning Outcome | EA Stage 1 Competencies |
|---|---|
| 1. Describe aspects of linear system theory. | PE1.1, PE1.2, PE1.3, PE3.4 |
| 2. Describe aspects of robust control theory. | PE1.1, PE1.2, PE1.3, PE3.4 |
| 3. Describe aspects of optimal and robust filtering. | PE1.1, PE1.2, PE1.3, PE3.4 |
| 4. Describe case studies from biomedical engineering and power systems. | PE1.4, PE1.5, PE1.6, PE2.1, PE2.2, PE2.4, PE3.1, PE3.3, PE3.4 |
| 5. Solve problems in linear system theory. | PE1.2, PE2.3, PE3.2 |
| 6. Solve problems in robust control. | PE1.2, PE1.6, PE2.3, PE3.2, PE3.3 |
| 7. Solve problems in optimal and robust filtering. | PE1.2, PE1.5, PE2.2, PE2.3, PE3.2 |

## Teaching Strategies

The teaching in this course aims at establishing a good fundamental understanding of the areas covered

using:

Formal face-to-face lectures, which provide you with a focus on the core analytical material in the course, together with qualitative, alternative explanations to aid your understanding.

Assignments to practice in problem solving, and to assess your progress.

Take home examination to give the final test of competency.

Learning in this Course

You are expected to attend all lectures in order to maximise learning. You must prepare well for all lectures. In addition to the lecture notes, you should read relevant sections of the recommended text. Reading additional texts will further enhance your learning experience. Group learning is also encouraged. UNSW assumes that self-directed study of this kind is undertaken in addition to attending face-to-face classes throughout the course.

## Additional Course Information

Prerequisites and Assumed Knowledge

The main prerequisite for this course is ELEC3114. It is essential that you are familiar with a standard introductory undergraduate course on control engineering such as ELEC3114 before this course is attempted. The prerequisites also include some undergraduate courses on Linear Algebra and Probability.

## Assessment

| Assessment task | Weight | Due Date | Course Learning Outcomes Assessed |
|---|---|---|---|
| 1. Assignment 1 | 25% | out - week 4 ; due - week 7 | 1, 2, 3, 5, 6 |
| 2. Assignment 2 | 25% | out - week 7 ; due - week 9 | 1, 2, 3, 5, 6 |
| 3. Final exam | 50% | out - week 9 ; due - 20 days later | 2, 3, 4, 5, 6, 7 |

### Assessment 1: Assignment 1

**Due date:** out - week 4 ; due - week 7

Take-home assignment.

### Assessment 2: Assignment 2

**Due date:** out - week 7 ; due - week 9

Take-home assignment.

### Assessment 3: Final exam

**Due date:** out - week 9 ; due - 20 days later

Take-home exam.

## Attendance Requirements

Students are strongly encouraged to attend all classes and review lecture recordings.

## Course Schedule

Workload

It is expected that you will spend at least ten to twelve hours per week studying a 6 UoC course, from Week 1 until the final assessment, including both face-to-face classes and independent, self-directed study. In periods where you need to need to complete assignments, the workload may be greater. Over-commitment has been a common source of failure for many students. You should take the required workload into account when planning how to balance study with employment and other activities.

Attendance

Regular and punctual attendance at all classes is expected. UNSW regulations state that if students attend less than 80% of scheduled classes they may be refused final assessment.

View class timetable

### Timetable

| Date | Type | Content |
|---|---|---|
| O-Week: 7 February - 11 February | Reading | Notes_set_1 |
| Week 1: 14 February - 18 February | Lecture | Review of Matrix Methods and SISO State Space Methods. |
| | Reading | Notes_set_1, notes_set_2. |
| Week 2: 21 February - 25 February | Lecture | Feedback Control of SISO Systems: Input/Output and State Space. |
| | Reading | Notes_set_3, notes_set_4, notes_set_5, notes_set_6 |
| Week 3: 28 February - 4 March | Lecture | Tracking and Disturbance Rejection, Introduction to MIMO systems. Polynomial Matrices and Smith-McMillan Form. |
| | Reading | Notes_set_7, notes_set_8, notes_set_9, notes_set_10 |
| Week 4: 7 March - 11 March | Lecture | MIMO Decomposition and Balanced Realizations. |
| | Reading | Notes_set_11, notes_set_12, notes_set_13 |
| | Assessment | Assignment 1 out. |
| Week 5: 14 March - 18 | Lecture | Introduction to Robust control, Kharitonov |

| | | |
|---|---|---|
| March | | theorem, edge theorem. Classical approach to robust control design, robust PID controllers, case studies. |
| | Reading | Notes_set_14. |
| | Assessment | Assignment 1. |
| Week 6: 21 March - 25 March | Assessment | Assignment1. |
| Week 7: 28 March - 1 April | Lecture | Optimal control: dynamic programming; linear quadratic optimal control problem; Riccati equations. |
| | Assessment | Assignment 1 due. Assignment 2 out. |
| Week 8: 4 April - 8 April | Lecture | Model predictive control, Kalman filtering, case studies. |
| | Reading | Notes_set_15, notes_set_16, notes_set_17. |
| | Assessment | Assignment 2. |
| Week 9: 11 April - 15 April | Lecture | H-infinity control, differential games; H-infinity filtering. |
| | | Notes_set_18, notes_set_19. |
| | Assessment | Assignment 2 due, Take-home exam out. |
| Week 10: 18 April - 22 April | Lecture | Case studies: robust control of biomedical systems, robust control of wind power systems. |
| | Reading | Notes_set_20, notes_set_21. |
| | Assessment | Take-home exam. |
| Study Week: 25 April - 28 April | Assessment | Take-home exam. |

# Resources

## Prescribed Resources

Software: • Matlab (including Simulink)

Textbooks Prescribed textbooks:

• R.C. Dorf and R.H.Bishop. Modern Control Systems. Addison Wesley.

• G.C. Goodwin, S.F. Graebe and M.E. Salgado. Control Systems Design. Prentice Hall.

• J.B. Burl. Linear Optimal Control. Addison Wesley.

Reference books:

• T. Kailath. Linear Systems. Prentice Hall.

• I.R. Petersen and A.V. Savkin. Robust Kalman Filtering for Signals and Systems with Large Uncertainties. Burkhauser, Boston.

• I.R. Petersen, V.A. Ugrinovskii and A.V. Savkin. Robust Control Design Using H-innity Methods. Springer-Verlag.

On-line resources

Moodle As a part of the teaching component, Moodle will be used to disseminate teaching materials, host forums and occasionally quizzes. Assessment marks will also be made available via Moodle: https://moodle.telt.unsw.edu.au/login/index.php. Mailing list Announcements concerning course information will be given in the lectures and/or on Moodle and/or via email (which will be sent to your student email address).

## Course Evaluation and Development

Continual Course Improvement

This course is under constant revision in order to improve the learning outcomes for all students. Please forward any feedback (positive or negative) on the course to the course convener or via the Course and Teaching Evaluation and Improvement Process. You can also provide feedback to ELSOC who will raise your concerns at student focus group meetings. As a result of previous feedback obtained for this course and in our efforts to provide a rich and meaningful learning experience, we have continued to evaluate and modify our delivery and assessment methods. In particular, several practical case studies have been developed based on past students' feedback. During the last two years, two new case studies have been developed/significantly modified.

# Academic Honesty and Plagiarism

## Academic Honesty and Plagiarism

Plagiarism is the unacknowledged use of other people's work, including the copying of assignment works and laboratory results from other students. Plagiarism is considered a form of academic misconduct, and the University has very strict rules that include some severe penalties. For UNSW policies, penalties and information to help you avoid plagiarism, see https://student.unsw.edu.au/plagiarism. To find out if you understand plagiarism correctly, try this short quiz: https://student.unsw.edu.au/plagiarism-quiz.

## General Conduct and Behaviour

Consideration and respect for the needs of your fellow students and teaching staff is an expectation. Conduct which unduly disrupts or interferes with a class is not acceptable and students may be asked to leave the class.

# Academic Information

## COVID19 - Important Health Related Notice

Your health and the health of those in your class is critically important. You must stay at home if you are sick or have been advised to self-isolate by NSW health or government authorities. Current alerts and a list of hotspots can be found here. **You will not be penalised for missing a face-to-face activity due to illness or a requirement to self-isolate**. We will work with you to ensure continuity of learning during your isolation and have plans in place for you to catch up on any content or learning activities you may miss. Where this might not be possible, an application for fee remission may be discussed.

If you are required to self-isolate and/or need emotional or financial support, please contact the Nucleus: Student Hub. If you are unable to complete an assessment, or attend a class with an attendance or participation requirement, please let your teacher know and apply for special consideration through the Special Consideration portal. To advise the University of a positive COVID-19 test result or if you suspect you have COVID-19 and are being tested, please fill in this form.

UNSW requires all staff and students to follow NSW Health advice. Any failure to act in accordance with that advice may amount to a breach of the Student Code of Conduct. Please refer to the Safe Return to Campus guide for students for more information on safe practices.

# Dates to note

Important Dates available at: https://student.unsw.edu.au/dates

# Student Responsibilities and Conduct

Students are expected to be familiar with and adhere to all UNSW policies (see https://student.unsw.edu.au/policy), and particular attention is drawn to the following:

## Workload

It is expected that you will spend at least **15 hours per week** studying a 6 UoC course, from Week 1 until the final assessment, including both formal classes and *independent, self-directed study*. In periods where you need to complete assignments or prepare for examinations, the workload may be greater. Over-commitment has been a common source of failure for many students. You should take the required workload into account when planning how to balance study with employment and other activities.

## Attendance

Regular and punctual attendance at all classes is expected. UNSW regulations state that if students attend less than 80% of scheduled classes they may be refused final assessment.

## Work Health and Safety

UNSW policy requires each person to work safely and responsibly, in order to avoid personal injury and to protect the safety of others.

## Special Consideration and Supplementary Examinations

You must submit all assignments and attend all examinations scheduled for your course. You can apply for special consideration when illness or other circumstances beyond your control interfere with an assessment performance. If you need to submit an application for special consideration for an exam or assessment, you must submit the application **prior to the start** of the exam or before the assessment is submitted, except where illness or misadventure prevent you from doing so. Be aware of the "fit to sit/submit" rule which means that if you sit an exam or submit an assignment, you are declaring yourself well enough to do so and cannot later apply for Special Consideration. For more information and how to apply, see https://student.unsw.edu.au/special-consideration.

## Administrative Matters

On issues and procedures regarding such matters as special needs, equity and diversity, occupational health and safety, enrolment, rights, and general expectations of students, please refer to the School and UNSW policies:

https://student.unsw.edu.au/guide

https://www.engineering.unsw.edu.au/electrical-engineering/resources

## Image Credit

Synergies in Sound 2016

## CRICOS

CRICOS Provider Code: 00098G

## Acknowledgement of Country

We acknowledge the Bedegal people who are the traditional custodians of the lands on which UNSW Kensington campus is located.

## Appendix: Engineers Australia (EA) Professional Engineer Competency Standard

| **Program Intended Learning Outcomes** | |
|---|---|
| Knowledge and skill base | |
| PE1.1 Comprehensive, theory based understanding of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline | ✓ |
| PE1.2 Conceptual understanding of the mathematics, numerical analysis, statistics, and computer and information sciences which underpin the engineering discipline | ✓ |
| PE1.3 In-depth understanding of specialist bodies of knowledge within the engineering discipline | ✓ |
| PE1.4 Discernment of knowledge development and research directions within the engineering discipline | ✓ |
| PE1.5 Knowledge of engineering design practice and contextual factors impacting the engineering discipline | ✓ |
| PE1.6 Understanding of the scope, principles, norms, accountabilities and bounds of sustainable engineering practice in the specific discipline | ✓ |
| Engineering application ability | |
| PE2.1 Application of established engineering methods to complex engineering problem solving | ✓ |
| PE2.2 Fluent application of engineering techniques, tools and resources | ✓ |
| PE2.3 Application of systematic engineering synthesis and design processes | ✓ |
| PE2.4 Application of systematic approaches to the conduct and management of engineering projects | ✓ |
| Professional and personal attributes | |
| PE3.1 Ethical conduct and professional accountability | ✓ |
| PE3.2 Effective oral and written communication in professional and lay domains | ✓ |
| PE3.3 Creative, innovative and pro-active demeanour | ✓ |
| PE3.4 Professional use and management of information | ✓ |
| PE3.5 Orderly management of self, and professional conduct | |
| PE3.6 Effective team membership and team leadership | |