ELEC4631
Continuous-Time Control System Design
Course Outline – Semester 1, 2017

Never Stand Still | Faculty of Engineering | School of Electrical Engineering and Telecommunications

Course Staff

Course Convener: Dr Hendra Nurdin, MSEB 645, h.nurdin@unsw.edu.au
Lecturer: Dr Hendra Nurdin
Tutor: Dr Hendra Nurdin

Consultations: You are encouraged to ask questions on the course material, after the lecture class times in the first instance, rather than via email. Lecturer consultation times will be advised in this course outline. You are welcome to email the tutor or laboratory demonstrator, who can answer your questions relating to the tutorials and labs. ALL email enquiries should be made from your student email address with ELEC4631 in the subject line, otherwise they will not be answered.

Course Details

Credits

This is a 6 UoC course and the expected workload is 10–12 hours per week throughout the 13 week semester.

Contact Hours

The course consists of 2 hours of lectures, a 1-hour tutorial, a 3-hour laboratory session each week (every two weeks for each individual student), and one consultation hour with the lecturer (if required). **Attendance will be taken for lectures, tutorials and laboratories. Please only attend lab groups that you signed up for.**

	Day	Time	Location
Lectures	Monday	10 am – 12 pm	Mat 103
Tutorials	Monday	3 pm – 4 pm	CLB 3 (start in Week 2)
Consultations	Monday	4.30 pm – 5.30 pm	MSEB 655 (start in Week 2)

The full lab schedule can be found at

http://classutil.unsw.edu.au/ELEC_S1.html - ELEC4631T1

Context and Aims

ELEC 4631 will give students an introduction to elements of modern control theory based on state space representations of dynamical systems. In recent years, modern systems and control theory has found numerous interesting applications in broad areas of automation, signal processing, communication, economics, finance, circuit analysis, mechanical and civil engineering, aeronautics, navigation and guidance etc. The purpose of this course is to expand the students' knowledge of the field of control engineering and systems and control theory by providing them with fundamental concepts and problem solutions from modern systems and control theory that are useful for the above mentioned applications.

The aims of the course are to:

1. Further enhance students' understanding of simple as well as more complex continuous-time control systems.
2. Give a deeper introduction to state-space representation of continuous-time control systems, particularly for single input single output (SISO) linear systems.
3. Help students to understand the importance of the system state.
4. Familiarise students with the stability concept for linear and nonlinear systems, and controllability and observability concepts for linear systems.
5. Give students an understanding of basic analysis and synthesis tools for state space control systems, including basic design techniques for nonlinear systems.
6. Provide opportunities for students to gain practical experience in the use of computer based state space design and analysis tools in Matlab and Simulink.

Pre-requisites and Assumed Knowledge

The pre-requisite for this course is ELEC3114 Control Systems. It is also essential that you are familiar with MATH2069, Mathematics 2A, and MATH2099, Mathematics 2B, before this course is attempted. Students are expected to be familiar and comfortable with:

- **Vector calculus:** functions of several variables, multivariable calculus, scalar fields, vector fields, gradients (MATH2069)
- **Linear algebra**: matrices, matrix inversion, matrix determinant, vectors, vector spaces, basis vectors, linearly independence, linear span of vectors, null/kernel spaces, characteristic equations, eigenvalues, eigenvectors, diagonalisation of a matrix, exponentiation of a matrix, Jordan canonical form (MATH2099)
- **Control systems:** Laplace transform, inverse Laplace transform, transfer functions, poles and zeros, feedback loop, steady-state error (ELEC3114)

Student Learning outcomes

After successful completion of the course, the student is expected to be able to:

1. Demonstrated understanding of the notion of stability and know how to analyse stability using the direct and indirect methods of Lyapunov.
2. Demonstrate the ability to analyse simple to moderately complex control systems (linear and nonlinear) using Lyapunov theory.
3. Demonstrate a satisfactory understanding of linear systems and the fundamental notions of controllability and observability.
4. Demonstrate the ability to apply concepts and methods from modern control theory to design state feedback controllers, observers, and output feedback controllers for linear systems.
5. Demonstrate the ability to synthesise control systems by convex optimization methodologies.
6. Demonstrate the ability to design tracking controllers for linear state space systems.
7. Demonstrate the ability to synthesise modern state space controllers using Matlab and Simulink.

This course is designed to provide the above learning outcomes which arise from targeted graduate capabilities listed in ***Appendix A***. The targeted graduate capabilities broadly support the UNSW and Faculty of Engineering graduate attributes (listed in ***Appendix B***). This course also addresses the Engineers Australia (National Accreditation Body) Stage I competency standard as outlined in ***Appendix C***.

Course description

Overview of systems and control engineering with emphasis on modern and post-modern developments. Mathematical tools: matrices, quadratic forms and eigenvalue decompositions. Modelling of linear time-invariant systems by using state space equations. Controllability and observability of linear time invariant systems. Linear quadratic regulator. Servo-regulator control. Lyapunov stability. Observers. State and output feedback control design. Optimisation based techniques.

Teaching Strategies

Delivery Mode

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;
- Tutorials, which allow for exercises in problem solving and allow time for you to resolve problems in understanding of lecture material;
- Laboratory sessions, which support the formal lecture material and also provide you with practical construction, measurement and debugging skills;
- Consultations with the lecturer outside of class hours, according to the scheduled times.

Learning in this course

You are expected to attend all lectures, tutorials, labs, and attempt quizzes and the mid-session exams in order to maximise learning. You must prepare well for your laboratory classes. Reading additional texts beyond the lecture notes 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.

Especially important are learning strategies that you have to adopt.

- Learning is effortful - you have to make the effort.

- You have to develop your own mental models for how things work. I can give you insights, but you have to develop your own “schema”.

- You learn from errors and from discovering misconceptions.

- You cannot do this just by listening or reading. You have to try things out.

- Firstly, close your books and explain and write down concepts for yourself or for friends. Check. If your concept is not complete and accurate, do it again. You learn through the tip of your pen.

- Do all the tutorial problems to test your new-found understanding.

- You learn by doing. Make sure you become competent in the laboratory. Always come prepared before attending the labs, and pace yourself to complete in-lab tasks and experiments within the assigned lab time.

- The ultimate test of whether you have learned something is whether you can use it next year, or when you begin working. Only your schema are enduring. You will forget details, and setting out to simply memorise things is worthless - of minor assistance for exams only

Indicative Lecture Schedule

Week No	Summary of Lecture Program
1	Brief review of linear algebra and vector calculus
2	Brief review of linear algebra and vector calculus
3	Dynamical systems, state stability, and Lyapunov functions
4	State-feedback control using Lyapunov functions
5	Linear time invariant state space systems. **Quiz 1**
6	Controllability, observability, and pole placement
7	Introduction to linear quadratic regulator (LQR) theory.
8	Observers, output feedback, and the first method of Lyapunov. **Mid-session exam**
9	An introduction to linear matrix inequalities (LMIs).
10	Controller and observer synthesis using LMIs. **Quiz 2**
11	State and output feedback control for reference tracking.
12	Introduction to multiple input multiple output (MIMO) LTI state-space systems. Review lecture. **Lab exam**
13	**Lab exam**

Tutorial classes

You should attempt all of your problem sheet questions in advance of attending the tutorial classes. The importance of adequate preparation prior to each tutorial cannot be overemphasized, as the effectiveness and usefulness of the tutorial depends to a large extent on this preparation. Group learning is encouraged. Answers for these questions will be discussed during the tutorial class and the tutor will cover the more complex questions in the tutorial class.

Tutorial problems should be treated as if they are assignments. Questions similar to (but not identical) to tutorial problems can be expected in the mid-session and final exams. Tutorial sessions start in Week 2 and tutorial attendance WILL be kept.

Laboratory program

The laboratory schedule is deliberately designed to provide practical, hands-on exposure to the concepts conveyed in lectures after they are covered in class. You are required to maintain a lab book for recording your observations. A lab book is an A4 size notebook containing a mix of plain pages and graph sheets. You have to purchase you own lab book from any store.

Laboratory attendance WILL be kept and you are expected to attend all five labs from Week 2 to Week 11.

Indicative Laboratory Schedule

Period	Summary of Laboratory Program
Weeks 2, 3	Lab 0
Weeks 4, 5	Lab 1
Weeks 6, 7	Lab 2
Mid-session break	
Weeks 8, 9	Lab 3
Week 10, 11	Lab 4
Week 12, 13	**Lab exams**

Laboratory Exemption

All students enrolled in this course for Semester 1, 2017 must attend and complete all labs. If, for medical reasons or due to some other acceptable emergencies, you are unable to attend a lab you will need to apply for a catch-up lab during another lab time (**note that a valid medical certificate or suitable proof of emergency must be submitted to the lecturer)**, as agreed to by the lecturer.

Assessment

The assessment scheme in this course reflects the intention to assess your learning progress through the semester. Ongoing assessment occurs through quizzes, lab sessions, lab exam, and the mid-semester exam.

Quiz 1	**Take home quiz in Week 5. Covers materials up to Week 5.**	**2%**
Mid-Session Exam	**Written 1.5 hour examination in Week 8 to test your ability to demonstrate your mastery of course materials up to Week 6 and ability to do analytical calculations.** **Exam will be on Monday Week 8,**	**30%**

	24 April 24 2017, either in class or in the evening from 6 pm to 7.30 pm (to be confirmed). **If in-class exam then lecture will be moved to the evening from 6 pm – 8 pm on the same day.**	
Quiz 2	**Take home quiz in Week 10. Covers materials from Week 6 to Week 10.**	**2%**
Lab Exams	**Written 1 hour exam based on tasks that should be completed during the lab sessions.**	**16%**
Final Examination	**Written 2 hour examination covering all lecture, tutorial, and, possibly, laboratory materials.**	**50%**

Quizzes

The two short take home quizzes are given to provide you with some feedback on some sections of the course. These should be done independently and honestly. Plagiarism is a serious academic misconduct that will entail a heavy penalty.

Laboratory Exam

To verify that you have achieved the practical learning outcomes for the course, you will be examined in the laboratory. Laboratory exams are closed book practical exams that include a test of your understanding of concepts and analytical calculations. The exam questions will be based on what you have learned in your laboratory classes and lectures, and marks will be awarded for the correct understanding of practical and relevant theoretical concepts, and correct use of Matlab.

Mid-Session Exam

The mid-session examination is a 1.5 hour closed-book exam that tests your general understanding of the course material, and is designed to give you feedback on your progress through the analytical components of the course. Questions may be drawn from any course material up to the end of Week 6. It may contain questions requiring some (not extensive) knowledge of laboratory material, and will definitely contain numerical and analytical questions. Marks will be assigned according to the correctness of the responses.

Final Exam

The exam in this course is a centrally-administered closed-book 2 hour written examination. The examination tests analytical and critical thinking and general understanding of the course material in a controlled fashion. Questions may be drawn from any aspect of the course (including laboratory), unless specifically indicated otherwise by the lecturer. Marks will be assigned according to the correctness of the responses.

Relationship of Assessment Methods to Learning Outcomes

	Learning outcomes						
Assessment	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Quiz 1	✓	✓	-	-	-		-
Mid-session exam	✓	✓	✓	-	-		-
Quiz 2	-	-	✓	✓	-		-
Lab exams	✓	-	-	✓	✓	-	✓
Final exam	✓	✓	✓	✓	✓	✓	-

Course Resources

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).

Lecture notes

Lecture notes will be posted on Moodle.

Further texts and references

Additional resources that will be useful as references besides the lecture notes are

1. Franklin, Powell and Emami-Naeini, Feedback Control of Dynamic Systems, 6th edition, Addison-Wesley.
2. Two courses EE263 “Introduction to Linear Dynamical Systems” and EE363 “Linear Dynamical Systems” at Stanford University (USA). All info available on the websites: http://www.stanford.edu/class/ee263/ and http://www.stanford.edu/class/ee363/

Other Matters

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 http://www.lc.unsw.edu.au/plagiarism. To find out if you understand plagiarism correctly, try this short quiz: https://student.unsw.edu.au/plagiarism-quiz.

Student Responsibilities and Conduct

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

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 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.

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.

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.

Keeping Informed

Announcements may be made during classes, via email (to your student email address) or via online learning and teaching platforms like Moodle. From time to time, UNSW will send important announcements via these media without providing any paper copy. Please note that you will be deemed to have received this information, so you should take careful note of all announcements.

Special Consideration and Supplementary Examinations

You must submit all assignments and attend all examinations scheduled for your course. You should seek assistance early if you suffer illness or misadventure which affects your course progress. All applications for special consideration must be **lodged online through myUNSW within 3 working days of the assessment**, not to course or school staff. For more detail, consult https://my.unsw.edu.au/student/atoz/SpecialConsideration.html.

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 myExperience 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 S1 2017 new data acquisition cards have been installed in the control laboratory computers. This will allow control experiments on real hardware to be executed from the integrated Matlab's Simulink and real-time workshop (RTW) environments, without relying on third party software.

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:
http://www.engineering.unsw.edu.au/electrical-engineering/policies-and-procedures
https://my.unsw.edu.au/student/atoz/ABC.html

Appendix A: Targeted Graduate Capabilities

Electrical Engineering and Telecommunications programs are designed to address the following targeted capabilities which were developed by the school in conjunction with the requirements of professional and industry bodies:

- The ability to apply knowledge of basic science and fundamental technologies;
- The skills to communicate effectively, not only with engineers but also with the wider community;
- The capability to undertake challenging analysis and design problems and find optimal solutions;
- Expertise in decomposing a problem into its constituent parts, and in defining the scope of each part;
- A working knowledge of how to locate required information and use information resources to their maximum advantage;
- Proficiency in developing and implementing project plans, investigating alternative solutions, and critically evaluating differing strategies;
- An understanding of the social, cultural and global responsibilities of the professional engineer;
- The ability to work effectively as an individual or in a team;
- An understanding of professional and ethical responsibilities;
- The ability to engage in lifelong independent and reflective learning.

Appendix B: UNSW Graduate Attributes

The course delivery methods and course content addresses a number of core UNSW graduate attributes, as follows:

- Developing scholars who have a deep understanding of their discipline, through lectures and solution of analytical problems in tutorials and assessed by assignments and written examinations.

- Developing rigorous analysis, critique, and reflection, and ability to apply knowledge and skills to solving problems. These will be achieved by the laboratory experiments and interactive checkpoint assessments and lab exams during the labs.
- Developing capable independent and collaborative enquiry, through a series of tutorials spanning the duration of the course.
- Developing digital and information literacy and lifelong learning skills through assignment work.

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

	Program Intended Learning Outcomes	
PE1: Knowledge and Skill Base	PE1.1 Comprehensive, theory-based understanding of underpinning fundamentals	✓
	PE1.2 Conceptual understanding of underpinning maths, analysis, statistics, computing	✓
	PE1.3 In-depth understanding of specialist bodies of knowledge	✓
	PE1.4 Discernment of knowledge development and research directions	
	PE1.5 Knowledge of engineering design practice	✓
	PE1.6 Understanding of scope, principles, norms, accountabilities of sustainable engineering practice	
PE2: Engineering Application Ability	PE2.1 Application of established engineering methods to complex 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	
PE3: Professional and Personal Attributes	PE3.1 Ethical conduct and professional accountability	
	PE3.2 Effective oral and written communication (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	✓