ENGG*6600 Special topics: Linear Systems with applications in Engineering
Fall 2016

UNIVERSITY of GUELPH
School of Engineering
(Revision 0: May, 2016)

1 INSTRUCTOR

Instructor: Julie Vale, Ph.D., P.Eng.
Office: THRN 2345, ext. 54863
Email: jvale@uoguelph.ca
Office hours: By appointment

2 LEARNING RESOURCES

2.1 Course Website

Course material, news, announcements, and grades will be regularly posted to the ENGG*6600 Courselink site. You are responsible for checking the site regularly.

2.2 Additional Resources

Lecture Information: Lecture notes will not be posted. It is your responsibility to take your own notes in class.

Assignments: Assignments are posted to courselink and/or assigned in class.

Additional Resources: Useful links and additional resources will sometimes be posted to the course’s courselink page. It is your responsibility to subscribe to the page or to regularly check for updates. There is no required text, however excerpts from the following will be suggested as resources

3 \textbf{ASSESSMENT}

3.1 \textbf{Dates and Distribution}

There are three parts to this course: assignments (40%), report (short paper or long proof) (20%), and a final exam (40%). There are 9 assignments, due weekly in lectures 2-10, submitted in class. Assignments are done in groups. The report is individual.

The report grade is divided in two parts. 15/20 marks are awarded for the report itself. 5/20 marks are awarded during in-class discussion in weeks 10 and 11 (specific dates are dependent on the number of students in the class).

Details of the assignments and the report will be provided as the term progresses.

\textbf{Any late submissions will receive a grade of zero.}

The final exam will be scheduled at the first class meeting.

3.2 \textbf{Course Grading Policies}

\textbf{Passing grade} To pass this course you must achieve a grade of 65\% or higher.

\textbf{When You Cannot Meet a Course Requirement:} When you find yourself unable to meet an in-course requirement because of illness or compassionate reasons, please advise the course in writing, with your name, id#, and e-mail contact. See the graduate calendar for information on regulations and procedures for Academic Consideration:
http://www.uoguelph.ca/registrar/calendars/graduate/current/genreg/sec_d0e1400.shtml

\textbf{Accommodation of Religious Obligations:} If you are unable to meet an in-course requirement due to religious obligations, please email the course instructor within two weeks of the start of the semester to make alternate arrangements. See the undergraduate calendar for information on regulations and procedures for Academic Consideration of Religious Obligations:
http://www.uoguelph.ca/registrar/calendars/undergraduate/current/c08/c08-accomrelig.shtml
4 AIMS, OBJECTIVES & GRADUATE ATTRIBUTES

4.1 Calendar Description

Many complex, nonlinear, engineering systems can be approximated as linear ones. This course focuses on highly general linear system representations applicable to all engineering disciplines, specifically multi-dimensional, multi-input multi-output (MIMO) differential equations (for continuous time systems) and difference equations (for discrete time systems). The course provides a rigorous treatment of many applications of linear algebra tools, including generalized eigenvectors and eigenvalues, singular values, positive and negative (semi) definiteness, generalized metric spaces, induced norms, p-norms, and norm equivalence. From this basis, it then explores advanced linear time-invariant systems in the context of state-space representations, including solutions to the equations, proofs of linearity, stability (including the theorem of preservation of stability for non-linear systems), minimal representations and system reduction (using similarity transform), and over or under actuated/sensed systems. These concepts are extended to the advanced problem of linear time-varying systems. The end of the course will investigate the application of these tools for student interest topics (e.g., Markhov parameterization, optimization, performance limitations, advanced modeling, and advanced control, etc.). Students will be encouraged to apply these tools to their research projects via an in course project.

As part of the course, students will learn how to write mathematics for scholarly articles - this material will be woven into each lecture and will help students understand the subtleties in the technical material while becoming more precise and rigorous in their thinking. Additionally, MATLAB will be used in class and on assignments to provide illustrative examples and problems.

Prerequisite(s): ENGG*1500 or equivalent, MATH*2270 or equivalent

4.2 Course Aims

Success in this course requires the fundamentals of engineering mathematics (linear algebra, trigonometry, complex numbers, calculus, differential equations, and the Laplace transform), and the basics of systems and control (feedback, stability, first and second order systems).

This course explores the fundamentals of linear systems and develops more rigorous and precise mathematical thinking and writing.

4.3 Learning Objectives

At the end of this course, successful students will be able to

1) Perform basic linear algebra operations (by hand and in MATLAB), including row and column rank, determinant, generalized inversion, matrix exponential, similarity transform, trangularization, diagonalization, identification and application of positive or negative (semi) definite, obtaining generalized left and right eigenvalues and vectors, Jordan blocks, obtaining singular values, calculating norms on vectors and matrices, determining induced norms, identifying metric spaces, and finding solutions to systems of equations.

2) Formally and rigorously prove results related to the tools in 1)
3) Apply the operations in 1) to prove results for systems of linear (time varying and time invariant) differential equations, including issues of stability, existence and uniqueness, and minimality (including over and under actuation/sensing).

4) Write a short scholarly article or a rigorous mathematical proof using best practices for precise and accurate communication of mathematics, including punctuation, notation, and formatting.

4.4 Instructor’s Role and Responsibility to Students

The instructor’s role is to develop and deliver course material in ways that facilitate learning for a variety of students. Selected lecture notes will be made available to students on Courselink/D2L but these are not intended to be stand-alone course notes. During lectures, the instructor will expand and explain the content of notes and provide example problems that supplement posted notes. Scheduled classes will be the principal venue to provide information and feedback for tests and project.

4.5 Students’ Learning Responsibilities

Students are expected to take advantage of the learning opportunities provided during lectures and tutorials. Students, especially those having difficulty with the course content, should also make use of other resources recommended by the instructor. Students who do (or may) fall behind due to illness, work, or extra-curricular activities are advised to keep the instructor informed. This will allow the instructor to recommend extra resources in a timely manner and/or provide consideration if appropriate.

E-mail and Communication: As per university regulations, all students are required to check their uoguelph.ca e-mail account regularly: e-mail is the official route of communication between the University and its students. Please use lectures and lab help sessions as your main opportunity to ask questions about the course. Major announcements will be posted to the course website. It is your responsibility to check the course website regularly.

Recording of Materials: Presentations which are made in relation to course work—including lectures—cannot be recorded in any electronic media without the permission of the presenter, whether the instructor, a classmate or guest lecturer.

5 Teaching and Learning Activities

5.1 Timetable

Lectures:
TBD

5.2 Lecture Schedule

<table>
<thead>
<tr>
<th>Topic</th>
<th>How to write math</th>
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<tbody>
<tr>
<td>Week 1:</td>
<td>Mathematical preliminaries: review of core concepts required for the course, e.g., determinant, rank (row and column), inverse (including pseudo inverse), Laplace transform, state-space form</td>
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<tr>
<td>Week 2:</td>
<td>Basis, eigenvalues, right and left eigenvectors, and singular values: what are they, how do you calculate them, and what do they tell us?</td>
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<td>Week 3:</td>
<td>Similarity transform, Jordan blocks, generalized eigenvectors, block matrices and diagonalization, and applications.</td>
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<td>Week 4:</td>
<td>Generalized metric spaces, induced norms, p-norms, and norm equivalence, including proofs.</td>
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<td>Week 5:</td>
<td>Introduction to statespace: systems of linear time invariant differential/difference equations and their solutions, including the matrix exponential and convolution</td>
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<td>Week 6:</td>
<td>Statespace part 2: Linear time varying systems and their solutions, including the state transition matrix</td>
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<td>Week 7:</td>
<td>Stability.</td>
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<td>Week 8:</td>
<td>System minimization: over and under actuated/sensed systems (including PBL test and associated proofs)</td>
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<td>Week 9:</td>
<td>Nonlinear systems: finding linear approximations. Includes the theorem of preservation of stability and phase plots (including meta-stability, saddles and spirals).</td>
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<td>Week 10-12:</td>
<td>Discussion of student projects, and student driven applications such as optimization, image processing, robotics, advanced modeling and/or advanced control</td>
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### 5.3 Other Important Dates

**Drop Date:** The last date to drop one-semester courses, without academic penalty, is Friday, November 4, 2016. Refer to the Graduate Calendar for the schedule of dates: http://www.uoguelph.ca/registrar/calendars/graduate/current/sched/sec_d0e736.shtml

### 6 Lab Safety

There is no lab in this course; however, please note that safety is critically important to the School and is the responsibility of all members of the School: faculty, staff and students. As a student in a lab course you are responsible for taking all reasonable safety precautions and following the lab safety rules specific to
the lab you are working in. In addition, you are responsible for reporting all safety issues to the laboratory supervisor, GTA or faculty responsible.

## 7 Academic Misconduct

The University of Guelph is committed to upholding the highest standards of academic integrity and it is the responsibility of all members of the University community faculty, staff, and students to be aware of what constitutes academic misconduct and to do as much as possible to prevent academic offences from occurring. University of Guelph students have the responsibility of abiding by the University’s policy on academic misconduct regardless of their location of study; faculty, staff and students have the responsibility of supporting an environment that discourages misconduct. Students need to remain aware that instructors have access to and the right to use electronic and other means of detection. The Academic Misconduct Policy is detailed in the Graduate Calendar:

http://www.uoguelph.ca/registrar/calendars/graduate/current/genreg/sec_d0e1687.shtml

Please note: Whether or not a student intended to commit academic misconduct is not relevant for a finding of guilt. Hurried or careless submission of assignments does not excuse students from responsibility for verifying the academic integrity of their work before submitting it. Students who are in any doubt as to whether an action on their part could be construed as an academic offence should consult with a faculty member.

### 7.1 Resources

The Academic Misconduct Policy is detailed in the Undergraduate Calendar:

http://www.uoguelph.ca/registrar/calendars/undergraduate/current/c08/c08-amisconduct.shtml

A tutorial on Academic Misconduct produced by the Learning Commons can be found at:

http://www.academicintegrity.uoguelph.ca/

The School of Engineering has adopted a Code of Ethics that can be found at:

http://www.uoguelph.ca/engineering/undergrad-counselling-ethics

The Graduate Calendar is the source of information about the University of Guelph’s procedures, policies and regulations which apply to graduate programs:

http://www.uoguelph.ca/registrar/calendars/graduate/current/

## 8 Accessibility

The University of Guelph is committed to creating a barrier-free environment. Providing services for students is a shared responsibility among students, faculty and administrators. This relationship is based on respect of individual rights, the dignity of the individual and the University community’s shared commitment to an open and supportive learning environment. Students requiring service or accommodation, whether due
to an identified, ongoing disability for a short-term disability should contact the Centre for Students with Disabilities as soon as possible. For more information, contact CSD at 519-824-4120 ext. 56208 or email csd@uoguelph.ca or see the website: http://www.csd.uoguelph.ca/csd/.