

Course Outline (W2023)

BME639: Control Systems and Bio-Robotics

Instructor(s)	Dr. Owais Khan [Coordinator] Office: ENG328 Phone: (416) 979-5000 x 556096 Email: owaiskhan@torontomu.ca Office Hours:
Calendar Description	Introductory course for Biomedical Engineers: system modeling, simulation, analysis and classical-controller designs of linear, time-invariant, continuous time systems. System dynamic properties in time and frequency domains, performance specifications and basic properties of feedback are investigated. Stability analysis is reinforced through Routh-Hurwitz criterion, Root-Locus method, Bode plots, and Nyquist criteria. Concept of Bio-Robotics is introduced, and exposure to basics of state-space representation and feedback. Key control concepts are experienced through laboratory experiments using modular servo-system with open architecture, fully integrated with MATLAB and Simulink; use of simulation tools; and solving design problems.
Prerequisites	BME 532, CEN 199
Antirequisites	ELE 639
Corequisites	None
Compulsory Text(s):	<ol style="list-style-type: none"> 1. Automatic Control Systems, 10th Edition, Benjamin C. Kuo and Farid Golnaraghi, 2017, McGraw Hill Education 2. BME639: Lecture Notes, The lecture notes are available from the secure course website as PDF downloadable files. 3. MATLAB User Manual (including Control Systems Toolbox and Simulink) the Mathworks, Inc., Copyright 1995-2018, available for download on the Departmental Network as Matlab help files.
Reference Text(s):	<ol style="list-style-type: none"> 1. Control Systems Engineering, Norman S. Nise, 7th edition, 2016, Wiley Inc. 2. Modern Control Systems, Katsuhiko Ogata, 5th Edition, 2011, Prentice Hall 3. Feedback Control of Dynamic Systems, 7th Edition, Gene F. Franklin, J. Da Powell, Abbas Emami-Naeini, 2014, Pearson
Learning Objectives (Indicators)	<p>At the end of this course, the successful student will be able to:</p> <ol style="list-style-type: none"> 1. Demonstrate competency in modeling and analysis of a SISO, continuous, LTI control system in a single feedback loop configuration, including specific tasks of defining a system analytical description, its stability and its dynamic response. (2b) 2. Determine transfer function model of the DC servo motor by applying two methods. First, the theoretical method, by applying the mathematical and scientific principles. Second, the experimental method, by using the real-time experimental data. Then compare the results of the theory and the experiment and explain the behaviour of the process. This includes obtaining and verifying experimental data, assessing the accuracy of the results and explaining sources of possible discrepancies. (3a)

3. Implement a PI controller on the obtained model by simulation and on the real-time actual DC servo motor. Compare the control system results. Determine the existing constraints in the real-time control and explain their effects on the control systems. **(3b)**
4. Identify and then carry out steps required in designing a single loop controller (PID, Lead, Lag and State-feedback) for a low order LTI system to meet a set of specifications and then evaluate the controller design by verifying its performance against a set of criteria. **(4a)**
5. Identify and then carry out steps required in designing a simple in-the-loop controller (PID, Lead, Lag and State-feedback) for a low order LTI system to meet a set of specifications and then evaluate the controller design by verifying its performance against a set of criteria. **(4b)**
6. Demonstrate proficiency in the use of high-performance engineering modeling and analysis software (Matlab and Simulink) for control system analysis and design in this course, and for subsequent engineering practice. **(5a)**
7. Work effectively as a member of a team in the laboratory, manage the time to complete the lab projects appropriately in the given time schedule and submit the lab report according to the submission due date. Produce a lab summary individually and submit it with along the lab report to explain the teamwork has been done to achieve the goals of the lab project. **(6a)**
8. Produce a technical report using appropriate format, grammar, and citation styles, with figures and tables are carefully chosen to illustrate points made, with appropriate size, labels, and references in the body of the report, and respond appropriately to verbal questions from instructors - lab interviews. **(7a), (7b), (7c)**
9. Involve and play an active role in the lab projects, take a responsibility to complete the part of the lab project that has been assigned to do and produce a technical lab report for the assignment. **(8b)**

NOTE: Numbers in parentheses refer to the graduate attributes required by the Canadian Engineering Accreditation Board (CEAB).

Course Organization

6.0 hours of lecture per week for 13 weeks
 3.0 hours of lab per week for 12 weeks
 0.0 hours of tutorial per week for 12 weeks

Teaching Assistants

Dylan Young (Dylan.young@torontomu.ca)
 Sarina Taki (Sarina.taki@torontomu.ca)

Course Evaluation

Theory	
Quizzes (2 x 7%)	14 %
Midterm Test	20 %
Final Exam	45 %
Laboratory	
Labs 1-3 (3 x 7% in pairs)	21 %
TOTAL:	100 %

Note: In order for a student to pass a course, a minimum overall course mark of 50% must be obtained. In addition, for courses that have both "**Theory and Laboratory**" components, the student must pass the Laboratory and Theory portions separately by achieving a minimum of 50% in the combined Laboratory components and 50% in the combined Theory components. Please refer to the "**Course Evaluation**" section above for details on the Theory and Laboratory components (if applicable).

Examinations	Midterm exam in Week 7 during the Lecture time, two hours, problem solving, closed book (covers Week 1-6). Final exam during exam period, closed-book (covers Weeks 1-13).
Other Evaluation Information	There are assignment problems for each chapter posted on the course D2L. The assignment will not be collected. However, students are expected to solve the assignment problems.
Other Information	Lab marks are based on attendance, successful completion of pre-lab problems, participation, completion of experiment steps, lab reports and successful reply to your TA questions during submission. Students will have the responsibility to achieve a working knowledge of the software packages that will be used in the lab. Students will work in groups of two.

Course Content

Week	Hours	Chapters / Section	Topic, description
Week 1	3	Chapter 1, 3	Introduction: Information session, General concepts of feedback and control systems, Closed-loop control versus Open-loop control, Differential Equations and Laplace Transform Review.
Week 2	3	Chapter 2.2, 4.1-4.2	System Modeling and Representation: Modeling of Electrical Networks, Transfer function representation, Block diagram rules and simplifications, Signal flow graphs Mason's Gain Formula.
Week 3	3	Chapter 7.1-7.5,7.8	Linear System Time Response: Transient response analysis, First-order systems, Second-order systems, Higher-order systems and dominant poles.
Week 4	3	Chapter 5, 7.6	Quiz1 1 Stability Analysis: BIBO stability definition, Characteristic polynomials, Poles and stability conditions of LTI systems, Routh-Hurwitz stability criterion, Steady-State error analysis of feedback systems.
Week 5	3	Chapter 9	Root Locus Analysis: Closed-loop pole relation to the loop gain, Root locus graphical method of pole representation, Magnitude and angle laws, Root-locus plotting rules.
Week 6	3	Chapter 7.7, 11.5	Root Locus Design: Static feedback design, Gain selection from root-locus, Dynamic compensation design, Effect of adding pole/zeros to root-locus, Lead/Lag networks Lead/Lag compensator design in time-domain.

			Winter Study Week
Week 7	3	Practice Problems	Midterm Test.
Week 8	3	Chapter 10.1-10.2	Frequency Response Analysis: Frequency response, Frequency-domain representation, Bode Diagram, Relation between magnitude and phase, Cross over frequency Bandwidth.
Week 9	3	Chapter 10.4-10.11	Frequency Response Analysis: Polar Plots Nyquist Diagram Nyquist stability criteria Relative stability, Stability margins, Gain margin and phase margins
Week 10	3	Chapter 11.1-11.5	Quiz2 1 Frequency Response Design: Lead/Lag compensator and P PI PD and PID controller design in frequency-domain
Week 11	3	Chapter 8.1-8.11	State-Space Analysis: State-space representation of systems, State diagrams and state variables, State-space equations from high-order differential equations, State transition matrix, Characteristic equation and eigenvalues.
Week 12	3	Chapter 8.12-8.19	State-Space Design: Controllability and Observability of Linear Systems, State feedback control, Tracking objectives, Pole placement method, State feedback with integral control
Week 13	3	Practice Problems	Course Review: Review of Controller Design in Frequency Domain: Lead/Lag and PID Examples. Wrap up.

Laboratory(L)/Tutorials(T)/Activity(A) Schedule

Week	L/T/A	Description
2-3	Lab 1.1	Lab # 1.1: Introduction to Simulink, Open-Loop Control vs. Closed-Loop Control
4-5	Lab 1.2	Lab # 1.2: Transient Response Analysis and Stability of 2nd and 3rd Order Systems.

6-7	Lab 2.1	Lab # 2.1: Transfer Function Modeling of Physical Systems and Control.
8-9	Lab 2.2	Lab # 2.2: Introduction to Lead and Lag Compensators
10-11	Lab 3.1	Lab # 3.1: Introduction to PI PD and PID Controllers
12-13	Lab 3.2	Lab # 3.2: State Space Modeling of Physical Systems and Control.

Policies & Important Information:

Students are reminded that they are required to adhere to all relevant university policies found in their online course shell in D2L and/or on [the Senate website](#)

1. In accordance with the Policy on TMU Student E-mail Accounts (Policy 157), Toronto Metropolitan University (TMU) **requires** that any electronic communication by students to TMU faculty or staff be sent from their official university email account;
2. Any changes in the course outline, test dates, marking or evaluation will be discussed in class prior to being implemented;
3. Assignments, projects, reports and other deadline-bound course assessment components handed in past the due date will receive a mark of ZERO, unless otherwise stated. Marking information will be made available at the time when such course assessment components are announced.
4. Familiarize yourself with the tools you will need to use for remote learning. The [Continuity of Learning Guide](#) for students includes guides to completing quizzes or exams in D2L or Respondus, using D2L Brightspace, joining online meetings or lectures, and collaborating with the Google Suite.
5. The University has issued a minimum technology requirement for remote learning. Details can be found at: <https://torontomu.ca/covid-19/students/minimum-technology-requirements-remote-learning>. Please ensure you meet the minimum technology requirements as specified in the above link.
6. Toronto Metropolitan University COVID-19 Information and Updates (available <https://www.torontomu.ca/covid-19/students>) for Students summarizes the variety of resources available to students during the pandemic.
7. Refer to our **Departmental FAQ** page for information on common questions and issues at the following link: <https://www.ecb.torontomu.ca/guides/Student.Academic.FAQ.html>.

Missed Classes and/or Evaluations

When possible, students are required to inform their instructors of any situation which arises during the semester which may have an adverse effect upon their academic performance, and must request any consideration and accommodation according to the relevant policies as far in advance as possible. Failure to do so may jeopardize any academic appeals.

1. **Academic Consideration Requests for missed work** (e.g. missing tests, labs, etc) - According to [Senate Policy 134](#), Section 1.2.3, if you miss any exams, quizzes, tests, labs, and/or assignments for health or compassionate reasons you need to inform your instructor(s) (via email whenever possible) in advance when you will be missing an exam, test or assignment deadline. When circumstances do not permit this, you must inform the instructor(s) as soon as reasonably possible". *In the case of illness, a [Toronto Metropolitan Student Health Certificate](#), or a letter on letterhead from an appropriate regulated health professional with the student declaration portion of the Student Health Certificate attached. For reasons other than illness, proper documentation is also required (e.g. death certificate, police report, TTC report). **ALL supporting documentation for illness or compassionate grounds MUST be submitted within three (3) working days of the missed work.** **NOTE: You are required to submit all of your pertinent documentation through the University's online Academic Consideration Request system at the following link: prod.apps.ccs.torontomu.ca/senateapps.***
2. **Religious, Aboriginal and Spiritual observance** - If a student needs accommodation because of religious, Aboriginal or spiritual observance, they must submit a Request for Accommodation of Student Religious, Aboriginal and Spiritual Observance AND

- an Academic Consideration Request form within the first 2 weeks of the class or, for a final examination, within 2 weeks of the posting of the examination schedule. If the requested absence occurs within the first 2 weeks of classes, or the dates are not known well in advance as they are linked to other conditions, these forms should be submitted with as much lead time as possible in advance of the absence. Both documents are available at www.torontomu.ca/senate/forms/reobservforminstr.pdf. **If you are a full-time or part-time degree student, then you submit the forms to your own program department or school;**
3. **Academic Accommodation Support** - Before the first graded work is due, students registered with the [Academic Accommodation Support office](http://www.torontomu.ca/senateapps) (AAS - prod.apps.ccs.torontomu.ca/senateapps) should provide their instructors with an Academic Accommodation letter that describes their academic accommodation plan.

Virtual Proctoring Information (if used in this course)

Online exam(s) within this course may use a virtual proctoring system. Please note that your completion of any such virtually proctored exam may be recorded via the virtual platform and subsequently reviewed by your instructor. The virtual proctoring system provides recording of flags where possible indications of suspicious behaviour are identified only. Recordings will be held for a limited period of time in order to ensure academic integrity is maintained and then will be deleted.

Access to a computer that can support remote recording is your responsibility as a student. The computer should have the latest operating system, at a minimum Windows (10, 8, 7) or Mac (OS X 10.10 or higher) and web browser Google Chrome or Mozilla Firefox. You will need to ensure that you can complete the exam using a reliable computer with a webcam and microphone available, as well as a typical high-speed internet connection. Please note that you will be required to show your Toronto Metropolitan University OneCard prior to beginning to write the exam. In cases where you do not have a Toronto Metropolitan University OneCard, government issued ID is permitted.

Information will be provided prior to the exam date by your instructor who may provide an opportunity to test your set-up or provide additional information about online proctoring. Since videos of you and your environment will be recorded while writing the exam, please consider preparing the background (room / walls) so that personal details are not visible, or move to a room that you are comfortable showing on camera.

Academic Integrity

Toronto Metropolitan University's [Policy 60 \(the Academic Integrity policy\)](#) applies to all students at the University. Forms of academic misconduct include plagiarism, cheating, supplying false information to the University, and other acts. The most common form of academic misconduct is plagiarism - a serious academic offence, with potentially severe penalties and other consequences. It is expected, therefore, that all examinations and work submitted for evaluation and course credit will be the product of each student's individual effort (or an authorized group of students). Submitting the same work for credit to more than one course, without instructor approval, can also be considered a form of plagiarism.

Suspensions of academic misconduct may be referred to the Academic Integrity Office (AIO). Students who are found to have committed academic misconduct will have a Disciplinary Notation (DN) placed on their academic record (not on their transcript) and will normally be assigned one or more of the following penalties:

1. A grade reduction for the work, ranging up to and including a zero on the work (minimum penalty for graduate work is a zero on the work);
2. A grade reduction in the course greater than a zero on the work. (Note that this penalty can only be applied to course components worth 10% or less, and any additional penalty cannot exceed 10% of the final course grade. Students must be given prior notice that such a penalty will be assigned (e.g. in the course outline or on the assignment handout);
3. An F in the course;
4. More serious penalties up to and including expulsion from the University.

The unauthorized use of intellectual property of others, including your professor, for distribution, sale, or profit is expressly prohibited, in accordance with Policy 60 (Sections 2.8 and 2.10). Intellectual property includes, but is not limited to:

1. Slides
2. Lecture notes
3. Presentation materials used in and outside of class
4. Lab manuals

5. Course packs
6. Exams

For more detailed information on these issues, please refer to the [Academic Integrity policy](https://www.torontomu.ca/senate/policies/pol60.pdf) (<https://www.torontomu.ca/senate/policies/pol60.pdf>) and to the Academic Integrity Office website (<https://www.torontomu.ca/academicintegrity>).

Academic Accommodation Support

Toronto Metropolitan University acknowledges that students have diverse learning styles and a variety of academic needs. If you have a diagnosed disability that impacts your academic experience, connect with Academic Accommodation Support (AAS). Visit the [AAS website](#) or contact asadmin@torontomu.ca for more information.

Note: All communication with AAS is voluntary and confidential, and will not appear on your transcript.

Important Resources Available at Toronto Metropolitan University

1. [The Library](#) provides research [workshops](#) and individual assistance. If the University is open, there is a Research Help desk on the second floor of the library, or students can use the Library's virtual research help service at <https://library.torontomu.ca/ask> to speak with a librarian.
2. [Student Life and Learning Support](#) offers group-based and individual help with writing, math, study skills, and transition support, as well as [resources and checklists to support students as online learners](#).
3. You can submit an [Academic Consideration Request](#) when an extenuating circumstance has occurred that has significantly impacted your ability to fulfill an academic requirement. You may always visit the [Senate website](#) and select the blue radial button on the top right hand side entitled: Academic Consideration Request (ACR) to submit this request).

Please note that the Provost/Vice President Academic and Deans approved a COVID-19 statement for Fall 2022 related to academic consideration. This statement will be built into the Online Academic Consideration System and will also be on the [Senate website \(www.torontomu.ca/senate\)](http://www.torontomu.ca/senate) in time for the Fall term:

Policy 167: Academic Consideration for Fall 2022 due to COVID-19: Students who miss an assessment due to cold or flu-like symptoms, or due to self-isolation, are required to provide a health certificate. All absences must follow Senate [Policy 167: Academic Consideration](#).

Also NOTE: Policy 167: Academic Consideration does allow for a once per term academic consideration request without supporting documentation if the absence is less than 3 days in duration and is **not for a final exam/final assessment**. If the absence is more than 3 days in duration and/or is for a final exam/final assessment, documentation is required. For more information please see Senate [Policy 167: Academic Consideration](#).

4. [TMU COVID-19 Information and Updates for Students](#) summarizes the variety of resources available to students during the pandemic.
5. [TMU COVID-19 Vaccination Policy](#).
6. If taking a remote course, familiarize yourself with the tools you will need to use for remote learning. The Remote Learning guide for students includes guides to completing quizzes or exams in D2L Brightspace, with or without [Respondus LockDown Browser and Monitor, using D2L Brightspace](#), joining online meetings or lectures, and collaborating with the Google Suite.
7. Information on Copyright for [students](#).
8. At Toronto Metropolitan University (TMU), we recognize that things can come up throughout the term that may interfere with a student's ability to succeed in their coursework. These circumstances are outside of one's control and can have a serious impact on physical and mental well-being. Seeking help can be a challenge, especially in those times of crisis.

If you are experiencing a mental health crisis, please call 911 and go to the nearest hospital emergency room. You can also access these outside resources at anytime:

- **Distress Line:** 24/7 line for if you are in crisis, feeling suicidal or in need of emotional support (phone: 416-408-4357)
- **Good2Talk:** 24/7 hour line for postsecondary students (phone: 1-866-925-5454)
- **Keep.meSAFE:** 24/7 access to confidential support through counsellors via My SSP app or 1-844-451-9700

If non-crisis support is needed, you can access these campus resources:

- Centre for Student Development and Counselling: 416-979-5195 or email csdc@torontomu.ca
- Consent Comes First - Office of Sexual Violence Support and Education: 416-919-5000 ext: 553596 or email osvse@torontomu.ca

We encourage all Toronto Metropolitan University community members to access available resources to ensure support is reachable. You can find more resources available through the [Toronto Metropolitan University Mental Health and Wellbeing website](#).