Toronto Metropolitan University

Department of Electrical, Computer, & Biomedical Engineering
Faculty of Engineering & Architectural Science

Course Outline (W2024)

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
Corerequisites	None
Compulsory Text(s):	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):	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)	At the end of this course, the successful student will be able to: 1. Demonstrates understanding of control system representations, such as block diagrams, signal flow graphs, methods to analyze transient response. (**1c**) 2. Demonstrate understanding of stability analysis, such as root locus, Routh-Hurwitz criteria, Nyquist criterion, controller design (PD, PI, and PID) a, and state-space analysis. (**1d**) 3. 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**) 4. 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**)
5. 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**)
6. 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**)
7. 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**)
8. 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**)
9. 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**)
10. 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**)
11. 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

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

Teaching Assistants

TBA

Course Evaluation

Theory	
Midterm Exam	34 %
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	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	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.

University 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

Refer to the Departmental FAQ page for furhter information on common questions.

Important Resources Available at Toronto Metropolitan University

- 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 to speak with a librarian.
- 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.

- 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 radio button on the top right hand side entitled: **Academic Consideration Request (ACR)** to submit this request.

  For Extenuating Circumstances, Policy 167: Academic Consideration allows for a once per semester ACR request without supporting documentation if the absence is less than 3 days in duration and is not for a final exam/final assessment. Absences more than 3 days in duration and those that involve a final exam/final assessment, require documentation. Students must notify their instructor once a request for academic consideration is submitted. See Senate Policy 167: Academic Consideration.

- If a student is requesting accommodation due to a religious, Aboriginal and/or spiritual observance, they must submit their request via the online Academic Consideration Request (ACR) system **within the first two weeks of the class or, for a final examination, within two weeks of the posting of the examination schedule**. If the required absence occurs within the first two weeks of classes, or the dates are not known well in advance as they are linked to other conditions, these requests should be submitted with as much lead time as possible in advance of the required absence.

- 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.
- Information on Copyright for Faculty and students.

Accessibility

- Similar to an accessibility statement, use this section to describe your commitment to making this course accessible to students with disabilities. Improving the accessibility of your course helps minimize the need for accommodation.
- Outline any technologies used in this course and any known accessibility features or barriers (if applicable).

- Describe how a student should contact you if they discover an accessibility barrier with any course materials or technologies.

Academic Accommodation Support

Academic Accommodation Support (AAS) is the university's disability services office. AAS works directly with incoming and returning students looking for help with their academic accommodations. AAS works with any student who requires academic accommodation regardless of program or course load.

- Learn more about Academic Accommodation Support.
- Learn how to register with AAS.

Academic Accommodations (for students with disabilities) and Academic Consideration (for students faced with extenuating circumstances that can include short-term health issues) are governed by two different university policies. Learn more about Academic Accommodations versus Academic Consideration and how to access each.

Wellbeing Support

At Toronto Metropolitan University, 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 3596 or email osvse@torontomu.ca
- **Medical Centre:** call (416) 979-5070 to book an appointment

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.