

**ME 6409 -- Biomechanics of
Wearable Robotic Devices
Spring 2026**

Syllabus

Instructors:

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Course Textbook.

There is no required textbook.

Weekly readings from the primary scientific literature will be provided via Canvas.

Optional textbooks that can supplement required readings include:

1. *Introduction to Biomechanics (Materials, Circuits and Devices)*. 1st Edition. Graham M. Brooker. Scitech Publishing Inc. ISBN-13: 978-1891121272.
2. *Wearable Robots: Biomechatronic Exoskeletons*. Jose L. Pons. Wiley Publishing Inc. ISBN-13: 978-0470512944.
3. *Human Robotics: Neuromechanics and Control*. 5th Edition. Etienne Burdet et al. MIT Press. ISBN-13: 978-0-262-01953-8.
4. *Neuromechanics of Human Movement*. 5th Edition. Roger M. Enoka. Human Kinetics Publishing Inc. ISBN-13: 978-1450458801.
5. *Bioinspired Legged Locomotion: Models, Concepts Control and Applications*. 1st Edition. Maziar A. Sharbafi and Andre Seyfarth (Editors). Butterworth-Heinemann -Elsevier. ISBN-13: 978-0128037669.
6. *Biomechanics of Movement: The Science of Sports, Robotics, and Rehabilitation*. 1st Edition. Thomas Uchida and Scott Delp. MIT Press. ISBN-13: 978-0253330581

Course Description:

An introduction to the emerging science of human-machine interaction with particular focus on wearable robotic devices for restoration or augmentation of human movement. In parallel, students will learn basic principles of human neuromechanics and energetics (*i.e.*, the human machine) and gain exposure to the state-of-the-art in mechatronic design of wearable robotic systems.

Note: We welcome upper-level undergraduates and beginning graduate students with some background in one or more of the following disciplines: Mechanical Engineering, Biomedical

Engineering, Electrical and Computer Engineering and Biological Sciences--Applied Physiology and Kinesiology.

Suggested Previous Coursework:

-This is a graduate course with no formal prerequisites.

-Previous course work in one or more of the following areas is highly encouraged (not necessary to have all 3 completed, but some background is helpful).

A course in Matlab computing; *e.g.*, ME 2016 Computing Techniques or equivalent.

A course in System Dynamics; *e.g.*, ME 3017, BMED 3520, ECE3084 or equivalent.

A course in Biomechanics or Physiology of Human Movement; *e.g.*, BMED 3400 or BIOL/APPH 4200

-Students uncertain about preparedness should consult the instructors to seek advice about fitness to enroll.

Objectives: Course material will aim to give students a comprehensive understanding of the complex interaction between engineered wearable robotic systems and the underlying biological systems they seek to restore or augment.

Outline:

<u>Topics by Week</u>	<u>Dates</u>
1. Introduction: What are Wearable Robotic Devices?	M: Lecture <i>Case Example: DARPA Exo Program</i> W: Intro of Mod/Sim ModelSim: <i>Overview of Simple Hopper Zajac, Robertson et al.</i>
2. Principles of Locomotion Neuromechanics and Energetics	M: Official Holiday (no class) W: Lecture
3. Locomotion Measurement Techniques – Center of Mass Mechanics to Individual Muscle Neuromechanics	M: Lecture W: ModelSim: <i>MATLAB/Simulink 101</i> ModelSim: <i>Stim $u(t)$ to Act $a(t)$</i>

<p>4. Biological Actuation – How do skeletal muscle-tendons move the body?</p>	<p>M: Lecture + Case 1 <i>Case 1: Wounded Warrior – Ankle Weakness</i> W: <i>Lecture continued + ModelSim: Active Muscle Force --- FL and FV</i></p>
<p>5. Engineering Actuators for Wearable Robotic Systems</p>	<p>M: Lecture W: ModelSim: <i>Adding Elasticity Parallel + Series</i></p>
<p>6. Biological Sensing – How does the body sense itself and the environment?</p>	<p>M: Lecture W: <i>Case 2: Low Power Actuator Design</i> Modeling workshop Modeling Assignment #1 Due</p>
<p>7. Engineering Sensors for Wearable Robotic Systems.</p>	<p>M: Lecture + Modeling Project Team Formation W: ModelSim <i>Load/Environment Dynamics</i> <i>Hop Open-Loop</i></p>
<p>8. Biological Control – How does the nervous system regulate movement?</p>	<p>M: Lecture ModelSim: <i>Work on Project - Concept Modeling</i> W: <i>Case 3: Altered Sensory Feedback in Exos</i> Modeling Workshop</p>

<p>9. Engineering Control Systems for Wearable Robotics– Part I. – Low level Control</p>	<p>Modeling Assignment #2 Due M: Lecture W: <i>Project Team Meetings,</i></p>
<p>10. Engineering Control Systems for Wearable Robotics– Part II. – Mid-level Control</p>	<p>M: Lecture Proposals DUE W: <i>Project Team Meetings, Proposal review</i></p>
<p>11. Engineering Control Systems for Wearable Robotics– Part III. – High-level Control</p>	<p>M: Lecture W: <i>Case 4: MARSII Bionics Impedance Scheduling</i> ModelSim: <i>Work on Project</i></p>
<p>12. Engineering Control Systems for Wearable Robotics– Part IV. – Closed-Loop Physiological Control</p>	<p>M: Lecture W: ML Workshop: <i>Tutorial on ML Techniques in Matlab</i></p>
<p>13. Evaluation of Wearable Robots/Performance Outcomes</p>	<p>M: Lecture W: <i>Case 5: Machine Learning</i> ModelSim: <i>Work on Project</i></p>
<p>14. Wearables: Past, Present and Future</p>	<p>M: Lecture W: ModelSim: <i>Work on Project.</i></p>

<p>15. Final Project Week(s)</p>	<p>M: Final class <i>ModelSim:</i> <i>Work on Project.</i> W: Reading Day (no class)</p> <p>Final Exam Period Presentations and Celebration <i>Report DUE</i></p>
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Lecture:

Each week Monday’s class time will consist of a required in-person lecture that will focus on the assigned readings and background material on fundamental topics in biological and robotic subsystems that generate locomotion. Lectures are essential to provide knowledge necessary to complete the Case assignments. When available, we may post archival pre-recorded lectures in Canvas prior to Monday’s live session. Students are encouraged to watch these asynchronously prior to class to supplement the readings. This will help drive discussion/questions in class. Instructors will aim to post readings by Tuesday of the week before each lecture. To reiterate, students read the assigned papers before class, and can also watch the pre-recorded archival lecture when available.

Computer Modelling/Simulation (10% of grade):

There will be weekly interactive sessions will involve short lectures to introduce theory followed by breakout sessions for Matlab/Simulink model development. These coding sessions will guide students to implement a simple Hill-type muscle-tendon model during locomotion without a wearable device. There will be 2 short computer modeling and simulation assignments during the semester worth a total of 10%. Assignments will be to generate simulations across a parameter set of interest and document results in graphical format as part of a 1-2 page technical report. This will form the backbone for students to add a wearable robotic device to their model and study questions in human-machine interaction during projects in the course.

Case Study (select Fridays) (50% of grade):

For 5 of the weeks, Wednesday’s class time will consist of a ‘case-based’ discussion session. Cases will be problem descriptions devised by the instructors to reinforce lecture/journal article content by considering a ‘real-world’ scenario where the concepts can be applied. Instructors will aim to post cases around the start of the week before they are due.

For each of the 5 cases, each student will write a ~2 page executive summary outlining a solution to the given scenario. Guidelines will be provided by the instructors in the first week of class. The report is to be turned in before that week’s group discussion session (i.e., before class of that week’s case study). Instructors will grade the case-reports each time to be evaluated and provide a formal grade and feedback (~25%) via Canvas.

Next, each student will present a ~15 minute presentation outlining a case solution and motivating discussion, which they will lead, ~1 time during the semester (~15%). Students will be assigned a discussion timeslot in the first weeks of class.

Finally, a participation grade will also be assigned to each student based on turning in executive summaries and interaction during case discussions (~10%).

Final project (40% of grade):

There will be a final project due on the final exam date of the course. The final project will be comprised of a presentation and written report documenting a computer simulation of your own design set up to address a hypothesis-driven question relevant to wearable robotics. At ~mid-semester you will be expected to turn in a short project proposal (*i.e.*, Specific Aims) motivating the question you will address and describing the computer simulation you will build to test it. The model description should include a list of independent and dependent variables you will examine and a set of hypotheses regarding expected outcomes. The final written report will be a maximum of 6 pages and should be written similar to a journal paper (*i.e.*, Abstract, Introduction, Methods, Results, Discussion, Conclusion, References) (25%). The final presentation should be 15 minutes and flow like a journal article (15%).

<u>Category</u>	<u>Frequency [Grade Scheme]</u>	<u>% of Grade</u>
A. Case Studies -		
(i.) Executive Summary Solution	Hand-in ~bi-weekly;	25%
A. Case Studies -		
(ii.) Presentation/Discussion Lead	1 x Semester	15%
A. Case Studies -		
(iii.) Discussion Participation	Overall Impression	10%
B. Computer Simulations	2 x Semester	10%
C. Final Project	1 x Semester	
(i.) Written Report		25%
(ii.) Presentation		15%

For questions regarding A. Case Study, B. Computer Simulation and/or C. Final Project grading, please consult the instructors in person during office hours.

Grading:

The following percentages will be used to compute your final letter grade:

Grades will be attributed according to the usual scale:

90%	A
80%	B

70%	C
60%	D
<60%	F

Course website:

Canvas: <https://canvas.gatech.edu/>

ME-6409: <https://gatech.instructure.com/courses/352110>

We will upload assignments, reading material and other course material on Canvas under the course label: ME-6409.

We will also regularly post announcements. Check the site frequently for updated information. Electronic submissions of assignments should always be in .pdf format and only via the Canvas site. *Assignments submitted by email will not be graded.*

Policies:

- Late assignments: This is an upper-level, interactive course. Therefore assignments will not be accepted late without an instructor's permission.
- Collaboration: Students may discuss their assignments with each other, but homework and projects must be completed individually by each student. *You must turn in your own work.* Copying someone else's work and submitting it as your own will not be tolerated. If it is suspected that this has occurred, you will be reported to the Dean of Students for an honor code violation.
- Academic Misconduct: We expect compliance with Georgia Tech's Academic Honor Code. We will refer any evidence of cheating or other violations to the Dean of Students, with a recommendation that the penalty be a zero for the graded requirement and a one letter grade reduction in the course. Cheating includes, but is not limited to: using unauthorized references or notes, copying directly from any source, including friends, classmates, tutors or solution manuals; allowing another person to copy your work; taking an exam or handing in a graded requirement in someone else's name; having someone else take an exam or hand in a graded requirement in your name; asking for a re-grade of a document that has been altered from its original form. There is zero-tolerance for any violation of the Honor Code: If you are caught cheating, the consequences will be serious.
- Attendance policy: Students are expected to attend *all* sessions of the course unless deemed optional as specified in the syllabus. If you need to miss a class session, it is your responsibility to notify the instructors as far in advance as possible. In addition, it is your responsibility to obtain the corresponding notes from one of your classmates and to keep abreast of any announcement made in class by asking other students.
- Students with special needs: If you require special accommodations, please notify us as soon as possible (and provide me with your letter from the Office of

Disability Services) so that we can make appropriate arrangements. Note that there are no in-class exams or quizzes in this course.

- Student-Faculty Expectations Agreement: At Georgia Tech, we believe that it is important to strive for an atmosphere of mutual respect, acknowledgement, and responsibility between faculty members and the student body. The Student-Faculty Expectations articulate some basic expectations that you can have of me and that I have of you. In the end, simple respect for knowledge, hard work, and cordial interactions will help build the environment we seek. Therefore, I encourage you to remain committed to the ideals of Georgia Tech while in this class.