University of California, Berkeley
Department of Mechanical Engineering

MECENG 239 – Robotic Locomotion (4 units)
MEZANINNE /MECENG 139
Graduate and Undergraduate Elective

Syllabus

CATALOG DESCRIPTION

This course provides students with a basic understanding of robotic locomotion and the use of kinematics, dynamics, control algorithms, embedded microcomputers and mechanical components in designing artificial legs such as prosthetics, orthotics and exoskeletons.

COURSE PREREQUISITES

A preliminary course in the design and control of mechanical systems.

COURSE OBJECTIVES

1.The course objectives are to train students to be able to design artificial legs, select and design components of the robotic legs.

2. Conduct various analyses on the legs' performance, propose and study practical applications such as orthotics and prosthetics in medical field, back support, knee support and shoulder support exoskeletons in industrial field and recreational exoskeletons.

DESIRED COURSE OUTCOMES

Students completing this course will have the ability to design artificial legs for various recreational, industrial and medical applications. In designing such devices, students will be able to translate the desired device specifications or the wearer's performance into a set of meaningful engineering metrics. Knowing the desired metrics, students will be able to use the formal lectures (kinematics, dynamics, actuators, control algorithms, …) arrive at various components. Students will also be able to assess the performance of various artificial legs in combination with the individuals wearing them. The wearer's fatigue, change in the wearer's joint forces, and the agility of the wearer, using quantitative measures such as muscle EMG activities, oxygen consumption, heart rate and human operational bandwidth are some metrics representing the human- device performance.

TOPICS COVERED

Analysis of bipedal behavior in walking and running on level ground and inclined surfaces, basic kinematics of the robotic legs (forward kinematics, inverse kinematics, force-torque relations, trajectory planning), basic dynamics of the robotic systems (lagrange equations, virtual work theory, inverse dynamics), electric actuators (basic analysis and design parameters of dc motors, ac conduction motors, stepper motors, power devices such as h-bridges), hydraulic and pneumatic systems (basic mathematical models and design parameters of electro-hydraulic and pneumatic actuators, pumps, orifice performance, servo valves) , power transmission systems (basic theory of operation of planetary gears, harmonic drives, traction drives, belts, clutches), sensors (basic models and design parameters of encoders, tachometers, resolvers, hall effect sensor, piezoelectric sensors, and stain gauge sensors), locomotion control algorithms (multivariable control, robustness, modeling errors, unmolded dynamics, bandwidth, optimization, and various control methods)

CLASS/LABORATORY SCHEDULE

Three hours of lecture and three hours of lab per week.

COURSE SUPPORT

20-hour GSI and a 10-hour reader support for this course.

RELATIONSHIP OF THE COURSE TO ABET PROGRAM OUTCOMES

(a) An ability to apply knowledge of mathematics, science, and engineering.

(b) An ability to design and conduct experiments, as well as to analyze and interpret data.

(c) An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.

(d) An ability to function on multi-disciplinary teams.

(e) An ability to identify, formulate, and solve engineering problems.

(f) An understanding of professional and ethical responsibility.

(g) An ability to communicate effectively.

(h) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.

(i) A recognition of the need for, and an ability to engage in life-long learning.

(j) A knowledge of contemporary issues.

(k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

ASSESSMENT OF STUDENT PROGRESS TOWARD COURSE OBJECTIVES

20%: Homework assignments
20%: 2 midterm project presentation
60%: Final project

DETAILS FOR LECTURE AND FINAL PROJECT:

1. Formal lectures. Students receive a set of lectures on the design of artificial legs that use embedded microcomputers. The materials cover biological behavior of bipedal locomotion, kinematics and dynamics of 3D systems, electric and hydraulic actuators, sensors, power transmission systems, basic electronic devices, embedded microprocessor systems and control algorithms.

Projects. Students will design and construct various prototype artificial legs or their components such as actuators, sensors, control software, recognition, and machine learning algorithms
Individuals/groups will choose between 1 of 2 types of projects:

1. Undergraduate Students' Projects. The projects may focus on designing an artificial leg or a component of the artificial leg. For example, designing a new control algorithm, an actuator, a sensor will fall in this category. These projects usually focus of implementation of the lecture components potentially with some variations.

2. Graduate Students' Projects. These projects involve conducting a short-term research that manifests to a novel outcome worthy of publication in a peer-reviewed periodical or filing for patent. The graduate students may choose a component of their MS or PhD theses as their term project for this course. Further the students can continue this course project to become their MS or PhD theses.

In both cases, the students propose their research projects within two weeks after the start of the class where consent of the instructor is needed. The students will then present two review presentations to demonstrate their progress during the semester. A final demonstration and/or presentation of the project will take place during the last week of the class.

DIFFERENCE BETWEEN ROOM-SHARED ME139 AND ME239

Both courses will have the same set of lectures and homework assignments. ME139 will include a term project involving the design (and potentially construction) of a component or the whole artificial leg. This project, at minimum, is a practice of the learned materials in the class. ME239 includes a term project which will include a novel concept absent in the current literature. The objective here is to ensure students are able to develop a new design or a control algorithm worthy of publication in a robotics academic journal or conference proceeding. In situations, where the projects have potential to lead to a product, students will file for patents.

PERSON(S) WHO PREPARED THIS DESCRIPTION

Homayoon Kazerooni March 11, 2021

DETAILED WEEKLY SCHEDULE OF TOPICS

Topics

	topics	**readings**
2 weeks	bipedal behavior	book 1
2 weeks	basic kinematics of the robotic systems, forward kinematics, inverse kinematics, trajectory planning, some examples of planar and 3d robotic legs.	chapters 2, 3 and 4 of textbook 2
2 weeks	basic dynamics of the robotic systems, langrange's equations, inverse dynamics, force-torque relations	chapters 5 and 6 of textbook 2
2 weeks	electric actuators used in exoskeletons, prosthetics and	class notes and

	orthotics, dc motors theory, motor selection, pwm amplifier	selected chapters of textbook 3
2 weeks	hydraulic and pneumatic systems in exoskeletons, orthotics and prosthetics, pumps and motors, electro-hydraulic and pneumatic power elements, servovalves, actuators	selected chapters of books 4
2 weeks	power transmission (harmonic drives, planetary gears, traction drives, belts, clutches)	selected chapters of books 5 and 6
2 weeks	sensors (imu, encoders, resolvers, hall effect sensors, piezoelectric sensors, stain gauge sensors	selected chapters of books 5 and 6
2 weeks	locomotion control, survey of various control methods	recent selected papers

SUGGESTED TEXTBOOKS

1. Human Walking, Jessica Rose, Lippincott Williams & Wilkins
2. Robotics: Basic Analysis and Design, by William Wolovich, HRW Publications
3. Electric Motors and Their Controls by Tak Kenjo, Oxford Science Publications
4. Fundamentals of Hydraulic Engineering Systems, Robert J Houghtalen, A Osman Akan, and Ned Hwang, Pearson
5. Mechatronics System Design, Devdas Shetty and Richard Kolk, PWS Publishing
6. Mechatronics, Sabri Cetinkunt, John Wiley and Sons

SAMPLE OF A WEEKLY AGENDA

Week 1	general bipedal behavior	
Week 2	bipedal behavior, torque, power, kinematics	Project Formulation
Week 3	basic kinematics of the robotic systems, forward kinematics	
Week 4	inverse kinematics, trajectory planning	Assignment: Kinematics
Week 5	basic dynamics of the robotic systems, langrange's equations,	
Week 6	inverse dynamics, force-torque relations	Assignment: Dynamics
Week 7	electric actuators dc motors theory, motor selection, pwm amplifier	Project Presentation 1
Week 8	AC motors, stepper motors	Assignment: DC Motors, Basic motor control
Week 9	hydraulic and pneumatic systems, pumps and motors,	Assignment: Hydraulics
Week 10	servovalves	
Week 11	harmonic drives, planetary gears, traction drives, belts, clutches	Project Presentation 2
Week 12	encoders, resolvers, hall effect sensors, piezoelectric sensors, stain gauge sensors, imu	Assignment: Transmissions

Week 13	locomotion control	
Week 14	locomotion control	Assignment: Control
Week 15	Recent Publications	Final Project Demo, Technical Report

ABBREVIATED TRANSCRIPT TITLE (19 SPACES MAXIMUM): **Robotic Locomotion**
TIE CODE: [ss completes]
GRADING: Letter
SEMESTER OFFERED: Fall
COURSES THAT WILL RESTRICT CREDIT: None
INSTRUCTORS: H. Kazerooni
DURATION OF COURSE: 15 Weeks
EST. TOTAL NUMBER OF REQUIRED HRS OF STUDENT WORK PER WEEK: **Varies**
IS COURSE REPEATABLE FOR CREDIT? No
CROSSLIST: None