ME 403/503
Introduction to Robotics
Spring 2024

COURSE INFORMATION
Lecture:  Tuesday       12:40am – 1:30pm @ FENS L029
          Wednesday  11:40am – 1:30pm @ FENS G015
Recitation: Wednesday  3:40pm – 5:30pm @ FENS L067
Laboratory: Thursday   2:40pm – 4:30pm @ FENS L067
Credit: 4 credit hours

INSTRUCTOR
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TAs: Harun Tolasa, İlhami Osman Karakurt, Emre Yavaş

RESOURCES
Web Site: Available through SUCourse+. Please check regularly for announcements and updates.
Several copies of the book are available at the library.

PREREQUISITES AND CO-REQUISITES
A minimum grade of “D” from ENS206 or equivalent is a strictly enforced prerequisite. ME403R and ME403L are the co-requisites for the course. Attendance to ME403L is mandatory, while attendance to lectures and recitations are strongly encouraged. Students are also expected to have a working knowledge of differential equations, linear systems, statics, kinematics and dynamics. Familiarity with programming is recommended.

PURPOSE
This course is designed to equip students with fundamental theories and computational methodologies that are used in design and analysis of robotic systems. Students will learn how to analytically formulate kinematic and dynamic equations for robot manipulators, how to synthesize trajectory and force tracking controllers, as well as how to utilize numerical algorithms to simulate and real-time hardware-in-the-loop controllers to implement such closed-loop control systems.

During the first part of the course, students will be introduced to rigid motions in space and homogeneous transformations, forward and inverse kinematics at configuration and velocity levels, and Lagrange’s equations. Computer-aided dynamic simulations with numerical time integration methods will be exercised.

During the second part of the course, students will be introduced to path and trajectory planning methods, as well as fundamental techniques for robot control. In particular, independent joint control, multi-variable control, force and impedance control approaches will be introduced and implemented on the hardware.

The emphasis in this course is an integrated understanding of the kinematic/dynamic modeling and control concepts for robotic manipulators. Real-time hardware-in-the-loop implementation of the controllers is also emphasized such that students can experience the control challenges of the real world, such as sensor noise and unmodeled system dynamics.

This course involves a hands-on laboratory component (ME 403L) and a team project where the students are expected to implement their algorithms on sample robotic platforms.
**Homework**

Homework will be assigned regularly and posted on the course web site. Hard copies will not be made available in class.

**Exams**

There will be one midterm and one final exam. Since the course continually builds upon previous material, all exams will be comprehensive. In class exams are closed book, with one page of formulas supplied by the instructor.

**Lecture**

The lecture format will be loose. There may be a short break during the two hour lecture period. Extra lectures and problem solving sessions may be scheduled if necessary. Class participation and cooperation among students are highly encouraged. Student feedback will be collected throughout the semester and adaptation will be undertaken accordingly.

**Project/Take-Home Exam**

Students will be assigned a course project that will be graded as a take-home exam. The project topic will address a real life problem and aims to let students demonstrate their proficiency at a technical level.

**Tentative Grading Policy**

Your course grade is determined from the total points you receive from attendance, homework, midterm, project/take-home exam, laboratory assignments, and the final exam. Borderline grades are determined by class participation.

Homework must be submitted to the assigned teaching assistants by the end of the due date (5:00pm). **No late problem sets will be accepted.** (Extensions may be granted for special circumstances and only when requested at least one day in advance.)

You are responsible for all information given in class verbally and/or in writing. Any information about the course on the web may be replaced by the information given in the class.

Cooperative efforts at understanding the material and the assignments of the course are encouraged. You may also use the assignments of the previous years as exercises. However, you may only submit work that you have completed individually. For example, you may communicate verbally about methods for solving the assigned problems, but **sharing written work is not permitted.** Copying solutions from the assignments of the previous years or from internet resources (including any generative AI resources) is also **strictly forbidden.** Submitting any work that is not the result of a student’s own effort is considered cheating and will result in disciplinary action.

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<thead>
<tr>
<th>Homework Sets:</th>
<th>20%</th>
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<tbody>
<tr>
<td>Midterm Exam:</td>
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<tr>
<td>Laboratory Assignments:</td>
<td>20%</td>
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<tr>
<td>Take-Home Exam:</td>
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<tr>
<td>Final Exam:</td>
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<td><strong>Total:</strong></td>
<td>100%</td>
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**Other Notes**

Any student with a disability requiring accommodation in this course is encouraged to contact the instructor during the first two weeks of the semester.

Students whose attendance to exams is less than 50% will be assigned an “NA” grade.

Assignments and the term-project of graduate and undergraduate students are likely to differ from each other.
TENTATIVE SCHEDULE AND TOPICS

Introduction

Week 1
History
Highlights and Future
Terminology

Mathematics of Rigid Body Motion

Week 2 and 3
Vectors, Bases, Frames
Coordinate Vectors
Similarity Transformations
Rotations in Space and Topology of SO(3)
Representing Rotations
Homogeneous Transformations

Kinematics

Weeks 4 – 7
Kinematic Chains
Denavit-Hartenberg Convention
Forward Kinematics
Inverse Kinematics
Angular Velocity
Kinematic and Analytic Jacobian
Singularities
Static Force/Torque Relationship

Dynamics

Week 8 – 10
Holonomic Constraints and Virtual Work
Kinetic and Potential Energy
Inertia
Euler-Lagrange Equations
Properties of Robot Dynamic Equations
Numerical Integration of Equations of Motion

Robot Control

Weeks 11 – 14
Actuator and Drive Train Dynamics
Feed-forward Compensation
Independent Joint Control
Inverse Dynamics and Computed Torque Control
Passivity Based Control
Force and Impedance Control