Worcester Polytechnic Institute

RBE/ME 501 – ROBOT DYNAMICS
Department of Robotics Engineering
Spring 2024

COURSE AT A GLANCE

<table>
<tr><td>Instructor</td><td colspan="2">Loris Fichera, PhD
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Room 4808, 50 Prescott
https://www.wpi.edu/~lfichera</td></tr>
<tr><td>Teaching Assistants</td><td>Steven Hyland
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zzhong3@wpi.edu</td></tr>
<tr><td>Lectures</td><td colspan="2">M-W 4:00-5:20 pm
Unity Hall (UH) 400
Lectures will also be live streamed on Echo 360 – link will be posted</td></tr>
<tr><td>Office hours</td><td colspan="2">TBA</td></tr>
<tr><td>Course URL</td><td colspan="2">https://canvas.wpi.edu/courses/56195</td></tr>
<tr><td>Recommended Textbooks</td><td colspan="2">Lynch, K. M., & Park, F. C. (2017). Modern Robotics. Cambridge University Press. Available as free PDF download from:
https://hades.mech.northwestern.edu/index.php/Modern_Robotics
Siciliano, B., Sciavicco, L., Villani, L., & Oriolo, G. (2010). Robotics: modelling, planning and control. Springer. Available as free PDF download through the WPI library.</td></tr>
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Welcome to RBE 501! This course covers foundations and principles of robot dynamics. Topics include system modeling, including dynamical modeling of serial arm robots using Newton and Lagrange techniques; dynamical modeling of mobile robots; introduction to dynamics-based robot control; trajectory planning; singularity and manipulability. **Prerequisite Courses:** RBE 500 or equivalent.

About the instructor: Dr. Fichera is an Assistant Professor of Robotics Engineering, with courtesy appointments in Computer Science and Biomedical Engineering. His research interests are in medical robotics and image-guided surgery. An alumnus of the Italian Institute of Technology (PhD, 2015), he was a postdoc at Vanderbilt University before joining WPI in 2017. He leads the Cognitive Medical Technology (COMET) Laboratory, located at 50 Prescott, suite 4832.

The instructor reserves the right to modify the course outline and policies mentioned in this syllabus at any time during the term.

LEARNING OUTCOMES

By the end of this course, students will be able to:

1. Derive the equations of motion of serial robotic arms.
2. Implement physically-realistic robot simulations.
3. Perform torque-based control of serial robotic arms.
4. Evaluate and compare different numerical inverse kinematics algorithms.
5. Implement trajectory planning algorithms.

Each of the learning outcomes listed above contributes to one or more of the Robotics Program Student Outcomes. Check the last page of this document for more information.

COURSE LOGISTICS

- **First things first: Everybody is welcome in this course**, without distinction of nationality, ethnicity, social origins, gender identity, sexual orientation, or other status. The instructor shares the view that "*diversity is crucial […] to answer the next big questions for robotics as we integrate [the robots] more into our daily lives*[1]*".*
- **Communication:**
    - **With the instructor/TA/peers**: A discussion board will be set up on Piazza, and it will be accessible from the Canvas course website. Piazza will provide a forum to discuss questions around the course material, lectures, assignments, and expectations. You may ask questions, answer others' questions, discuss topics with your peers, etc. The teaching staff will check on the discussion board regularly to answer any unanswered questions.
    - **Private communication with the instructor/TA:** if you wish to communicate privately with either the instructor or the TA, feel free to message them on Piazza. You can also send an e-mail if you want, but you will get a faster response through Piazza.
    - **Timing of responses:** Allow up to 24 hours for responses on Piazza, and 48 hours for e-mails. Expect longer response times for messages sent during the weekend.
- **Assignments and grading:**
    - **Homework:** Homework consists of MATLAB-based problem sets. The objective of the homework is to guide students in the development of a library of MATLAB functions and scripts to solve robot dynamics problems. There will be a total of four homework assignments throughout the semester. Each homework will have two deadlines:
        - *Soft deadline*: Students who submit by the soft deadline will be given the opportunity to resubmit their work to improve their score once they have received initial feedback. Missing a soft deadline will not trigger any point penalty.

[1] A. Howard and M. Kennedy, "Robots are not immune to bias and injustice," Science Robotics, vol. 5, no. 48. American Association for the Advancement of Science, Nov. 25, 2020. doi: 10.1126/scirobotics.abf1364.

- *Hard deadline*: No submissions will be accepted after the hard deadline. If you anticipate needing more time to complete an assignment because of extenuating circumstances, you should inform the instructor as soon as possible.

- **Exams:** The course involves a mid-term exam and a final exam. These are individual assignments and are carried out in class. Students will need to use their own laptop. If you do not have a laptop, inform the instructor as soon as possible to set up a different arrangement.
- **Mini-Projects:** Mini-projects are practical open-ended problems where students deploy the techniques learned in the classroom. These assignments are carried out in simulation. Mini-projects only have hard deadlines.
- **Grading breakdown:** The final grade for the course will be determined as follows:
  - Homework assignments: 40%
  - Exams: 40% (*)
  - Mini-Projects: 20%

  (*) The score for the exams is calculated as follows: (0.75 x highest-scoring exam + 0.25 x lowest-scoring exam). *Example: A student gets 80 on the midterm exam and 95 on the final exam. The final exam score will be 0.75 x 95 + 0.25 + 80 = 91.25.*

- **Final Letter Grading Scheme: A** (100-90%), **B** (90-80%), **C** (80-70%), **F** (<70%)

- **Appeals:** Any appeals of assignment scores must be resolved within <u>one week</u> of the return of the graded assignment.

- **Academic Integrity Policy:**

  Review WPI's Academic Integrity Policies at:
  https://www.wpi.edu/about/policies/academic-integrity

  Rule of thumb: Any work that you present as your own should represent your own understanding of the material.

- **Attendance and participation:** attendance and active participation in lectures are strongly encouraged.

- **Student Accessibility Services:** Students with approved academic accommodations should plan to submit their accommodation letters through the Office of Accessibility Services Student Portal. Should you have any questions about how accommodations can be implemented in this particular course, please contact the instructor as soon as possible. Students who are not currently registered with the Office of Accessibility Services (OAS) but who would like to find out more information regarding requesting accommodations and what that entails should plan to contact them via email: AccessibilityServices@wpi.edu and/or via phone: (508) 831-4908.

TENTATIVE SCHEDULE

Class	Date	Topic	What is due?
1	Jan-10	Course Introduction	
-	Jan-15	*No class-MLK Day*	
2	Jan-17	Review of Robot Kinematics	
3	Jan-22	Exponential Coordinates of Rotation	
4	Jan-24	Exponential Coordinates of Rigid-Body Motion	
5	Jan-29	The Product of Exponentials Formula	
6	Jan-31	The Product of Exponentials Formula (Examples)	
7	Feb-5	Differential Kinematics, Jacobian in the Space Frame	
8	Feb-7	Adjoint Transformations	
9	Feb-12	Inverse Kinematics Algorithms	
10	Feb-14	Analysis of Manipulability, IK Algorithms (continued)	
11	Feb-19	Midterm Review I	
12	Feb-21	Midterm Review II	
-	Feb-26	*Midterm Exam*	
13	Feb-28	Guest Lecture (Speaker TBA)	
14	Mar-11	Kinematics in the Body Frame	
15	Mar-13	Statics + Newton-Euler Formulation of Dynamics	
16	Mar-18	Newton-Euler Formulation of Dynamics (continued)	
17	Mar-20	Newton-Euler Formulation of Dynamics (continued)	
18	Mar-25	Lagrangian Formulation of Dynamics	

19	Mar-27	Lagrangian Formulation of Dynamics (continued)	
20	Apr-1	Trajectory Generation	
21	Apr-3	Forward Dynamics & Dynamics in the Task Space	
22	Apr-8	Vision-Based Tracking	
23	Apr-10	Computed-Torque Control	
-	Apr-15	*No class-Patriots Day*	
24	Apr-17	Final Course Review I	
25	Apr-22	Final Course Review II	
-	Apr-24	*Final Exam*	
26	Apr-29	Guest Lecture (Speaker TBA)	

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DEPARTMENT OF ROBOTICS ENGINEERING – STUDENT OUTCOMES

Each of the Course Learning Outcomes (LOs) listed on page 2 of this syllabus addresses one or more of the RBE Department Student Outcomes (SOs) listed below:

- SO #1: Identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
- SO #2: Apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
- SO #3: Communicate effectively with a range of audiences
- SO #4: Recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
- SO #5: Function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
- SO #6: Develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
- SO #7: Acquire and apply new knowledge as needed, using appropriate learning strategies
- SO #8: Evaluate and integrate the mechanical, electrical, and computational components of a cyber-physical system
- SO #9: Recognize and take advantage of entrepreneurial opportunities

Our Course LOs relates to RBE Department SOs according to the following table:

		RBE Department Student Outcomes (SOs)												
		SO #1	SO #2	SO #3	SO #4	SO #5	SO #6	SO #7	SO #8	SO #9	HWs	Exams	Labs	Projs
Course Learning Outcomes (LOs)	LO #1	X					X				X	X		
	LO #2	X					X				X	X		X
	LO #3	X					X				X	X		
	LO #4	X					X	X			X	X		X
	LO #5	X					X				X	X		