Worcester Polytechnic Institute

RBE 3001 – UNIFIED ROBOTICS III: Manipulation
Department of Robotics Engineering
C Term 2024

COURSE AT A GLANCE

Instructors	Vince Aloi, PhD valoi@wpi.edu Room 276, Unity Hall https://wpi.edu/people/faculty/valoi	Loris Fichera, PhD lfichera@wpi.edu Room 4808, 50 Prescott St https://www.wpi.edu/~lfichera
Teaching Assistants	Dan Moyer dmoyer@wpi.edu	Wenpeng Wang wwang11@wpi.edu
Lectures	MTRF 11:00-11:50 am Unity Hall (UH) 500 Lectures will also be live streamed on Zoom – link will be posted	
Labs	(Section CX01) W 1:00-2:50 in Atwater Kent (AK), Room 120D (Section CX02) W 3:00-4:50 in Atwater Kent (AK), Room 120D	
Office hours	Vincent Aloi: UH 276 T 4:00 – 5:00	
Course URL	https://canvas.wpi.edu/courses/56630	
Recommended Textbooks	No textbook is required for this course. The following textbooks are suggested for supplementary reading: • Lynch, K. M., & Park, F. C. (2017). *Modern Robotics*. Cambridge University Press. Available as free 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.	

Welcome to RBE 3001! The focus of this course is on **robotic arms** and ***robotic manipulation***, i.e., the coordinated motion of multiple actuators to execute complex manipulation tasks in the physical space. We will study ***position*** and ***velocity kinematics***, and introduce fundamental concepts of ***robot dynamics***. Additional course topics include *motion planning and trajectory generation*, *vision-based tracking*, *error sources and propagation*. The theoretical methods learned in the classroom will be applied during practical laboratory sessions, which will culminate in the construction and programming of a 4 degrees-of-freedom robotic manipulator. The necessary concepts for robot programming will be introduced in MATLAB and C++. **Recommended background: RBE 2001 & 2002, ECE 2049, CS 2102, MA 2051, MA 2071**

The instructors reserve 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. Control a robotic arm to implement a pick-and-place task
2. Calculate the forward and inverse kinematics of serial robotic arms.
3. Derive the equations of motion of simple kinematic chains.
4. Evaluate the dexterity (manipulability) of serial robotic arms.
5. Use cameras as sensors to detect objects in the workspace of a robot.

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

COURSE LOGISTICS

- **First things first: Everybody is welcome in this course**, without distinction of gender identity, sexual orientation, nationality, race, social origins, or other status. We respect and appreciate the diverse experiences, beliefs, and skills of each and every student.

- **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 (see link on the cover page of this syllabus). 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 will be assigned regularly throughout the term, and it is to be turned in at (or uploaded prior to) the beginning of class on the date due, unless otherwise specified. Homework must be neatly hand-written or typed on single-sided, letter-size paper (for example, engineering paper) and must be submitted on time.
    i. **Submission Policy for Homework Assignments:** Assignments will be

docked 50% if turned in within 24 hours of the due date/time. No credit will be given for assignments turned in after this time. No extensions are given without prior notice and approved rationale (emergency). Any appeals of assignment scores must be resolved within one week of the return of the graded assignment.

- **Exams**: Three exams will be given as shown on the course schedule. Make-ups will only be granted with an acceptable excuse approved in advance.
    i. **Exam Calculator Policy:** No “connected” devices will be allowed during exams. Only models of calculators approved by The National Council of Examiners for Engineering and Surveying (NCEES) are permitted in the exams (Same requirements as for the EIT/PE Exams). You are responsible for bringing an approved calculator to exams, others (e.g. programmable calculators, smartphones, tablets, laptop computers, etc.) will not be allowed. For more information: http://ncees.org/exams/calculator-policy/
- **Laboratories:** Students are required to attend all of their scheduled lab sections and must complete all the lab activities. In order to get credit for the lab, a student must be an active participant in the team’s effort. All students on a lab team are expected to be involved in and understand all aspects of the lab. Lab grades will be based on assignments, quizzes, reports, and performance in the lab. Pre-lab assignments are due at the beginning of the day of each lab session and are graded on an individual basis. Overall lab grade will make up 40% of the total score with equal weight for each week (i.e. a 3-week lab counts 3x as much as a 1-week lab). A detailed handout on lab policies including guidelines for report writing and grading rubrics will be provided during the first lab session.
    i. **Submission Policy for Laboratory Reports:** There will be two deadlines for laboratory reports:
        1. *Soft deadlines*: Teams 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.
        2. *Hard deadlines*: 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 instructors as soon as possible.
- **Grading Breakdown:** The final grade for the course will be determined as follows:
    - Homework assignments: 15%
    - Exams: 45% (*)
    - Laboratory: 40%

  (*) The lowest scoring exam will be dropped from the calculation of the final grade
- **Final Letter Grading Scheme: A** (100-90%), **B** (90-80%), **C** (80-70%), **NR** (<70%)

- **Appeals:** Any appeals of assignment scores must be resolved within one week of the return of the graded assignment.
- **Academic Integrity Policy:**

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

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

The following is a (not comprehensive) list of examples of acceptable and unacceptable actions under this policy:

Acceptable	Unacceptable
Homework: ▪ Discussing a homework problem with someone else to gain a better understanding. ▪ Looking at a solution from a similar problem to get an idea of how to approach the problem at hand. ▪ Using generative AI tools (including, but not limited to ChatGPT, Google Bard, etc.) to get an idea of how to approach the problem at hand.	**Homework:** ▪ Copying material from someone else's solution and handing it in as your own. ▪ Copying a solution from a previous set, and handing it in as your own. ▪ Copying and pasting a solution provided by a generative AI model without being able to explain it or understand what it does.
Exams: ▪ Looking at exams and exam solutions from previous offerings of the course (if made available by the instructor). ▪ Using a calculator (as	**Exams:** ▪ Using calculator or other electronic device to access stored formulas or notes, or to access any other resource or collaboration during exam.

specified in the course policies) to perform numerical calculations.

Labs:

- Discussing the pre-lab with someone else to gain a better understanding
- Partners dividing tasks in lab; for instance, one person makes measurements and the other records data. In any case, all students must understand all aspects of the lab.
- Checking with another lab team to see if your data makes sense
- Looking at lab reports from previous RBE courses to get an idea of the correct reporting format.
- Forking a repository (e.g. a library) with commit attribution and git submodules is acceptable

Labs:

- Copying material from someone else's pre-lab and presenting it as your own.
- Only a subset of the team does the majority of the work, with other lab partner(s) not significantly attending, contributing, or understanding.
- Putting someone's name on a lab write-up when they made no contribution.
- Using other code, data, or write-up in place of your own.
- Using material from previous reports and presenting as your own.
- Copying source code and committing in bulk is not acceptable, must use version control and attribute credit where applicable.

- **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.

- **Students are encouraged to use campus support services**, which include the Academic Resources Center, the Writing Center and MASH (Math and Science Help).

TENTATIVE SCHEDULE

Week	Class/Lab	Day	Date	Topics	What is due?
1	Lecture 1	Wed	10-Jan	Course Introduction	
	Lecture 2	Thu	11-Jan	Fundamentals of Robot Kinematics	
	Lecture 3	Fri	12-Jan	Rotation Matrices	
2		Mon	15-Jan	MLK day – no class	
	Lecture 4	Tue	16-Jan	Intro to the RBE 3001 hardware Homogeneous Transformation Matrices	***Homework 1***
	Lab 1	Wed	17-Jan	**Lab 1:** System architecture and joint-level control	***Prelab 1***
	Lecture 5	Thu	18-Jan	The Denavit Hartenberg Convention	
	Lecture 6	Fri	19-Jan	Forward kinematics of typical manipulator structures	
3	Lecture 7	Mon	22-Jan	Forward kinematics of typical manipulator structures (continued)	
	Lecture 8	Tue	23-Jan	Path planning and trajectory generation	***Lab 1 Report***
	Lab 2	Wed	24-Jan	**Lab 2:** Forward Kinematics & Trajectory Generation	***Prelab 2***
	Lecture 9	Thu	25-Jan	Inverse Kinematics	
	Lecture 10	Fri	26-Jan	Inverse Kinematics Part II - Examples	***Homework 2***
4	Lecture 11	Mon	29-Jan	Exam review	
		Tue	30-Jan	**Exam 1 – Forward and Inverse kinematics**	***Lab 2 Report***
	Lab 3	Wed	31-Jan	**Lab 3:** Inverse Kinematics	**Prelab 3**
	Lecture 12	Thu	1-Feb	Inverse Kinematics Examples	
	Lecture 13	Fri	2-Feb	Differential kinematics	
	Lecture 14	Mon	5-Feb	Differential kinematics (continued)	

5	Lecture 15	Tue	6-Feb	Differential kinematics (continued)	***Lab 3 Report***
	Lab 4	Wed	7-Feb	**Lab 4:** Differential kinematics	
	Lecture 16	Thu	8-Feb	Computer Vision Part I: Image Processing	***Homework 3***
		Fri	9-Feb	Wellness day – no class	
6	Lecture 17	Mon	12-Feb	Computer Vision Part II: Camera calibration	
		Tue	13-Feb	Robots and Forces part I: Statics	
	Lab 5	Wed	14-Feb	**Lab 5:** Final project	
	Lecture 18	Thu	15-Feb	Exam 2 Review	**Lab 4 Report**
	Lecture 19	Fri	16-Feb	**Exam 2 – Differential kinematics**	
7	Lecture 20	Mon	19-Feb	Robots and Forces part II: Lagrangian Dynamics	
	Lecture 21	Tue	20-Feb	Robots and Forces part III: Dynamics of multi-link systems	
	Lab 6	Wed	21-Feb	**Lab 6:** Final project (continued)	**Draft of final project report**
		Thu	22-Feb	No class – Academic Advising day	
	Lecture 22	Fri	23-Feb	The Universal Robot Description format	***Homework 4***
8	Lecture 23	Mon	26-Feb	Final Course Review	
		Tue	27-Feb	Guest Lecture (TBA)	
	Lab 7	Wed	28-Feb	**Lab 7:** Final project (continued)	**Lab 5 Sign-offs**
		Thu	29-Feb	Exam 3 Review	
		Fri	1-Mar	**Exam 3 – Final Exam**	**Final Project Report**

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)									**Measured by**				
		SO #1	**SO #2**	**SO #3**	**SO #4**	**SO #5**	**SO #6**	**SO #7**	**SO #8**	**SO #9**	HWs	Exams	Labs	Projs	Others (Specify)
Course Learning Outcomes (LOs)	**LO #1**	X				X	X		X		X	X	X		
	LO #2	X				X	X		X		X	X	X		
	LO #3	X				X	X		X		X	X	X		
	LO #4	X				X	X		X		X	X	X		
	LO #5	X				X	X		X		X	X	X		

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