Worcester Polytechnic Institute

RBE 522 – CONTINUUM ROBOTICS
Department of Robotics Engineering
Fall 2022

COURSE AT A GLANCE

Instructor	Loris Fichera, PhD lfichera@wpi.edu Room 4808, 50 Prescott https://www.wpi.edu/~lfichera
Lectures	Mon-Thu 4:00-5:50 pm Fuller Labs (FL) 311
Office hours	TBA
Course URL	https://canvas.wpi.edu/courses/38153
Recommended Readings	Reading materials for this course consist primarily of peer-reviewed papers which will be posted on the Canvas site.

Welcome to RBE 522! Continuum robotics focuses on the study of "continuously flexible" robotic arms. This branch of robotics takes inspiration from flexible animal appendages (e.g., elephant trunks and octopus tentacles) to create manipulators capable of complex bending motions. Real-world applications of continuum robots include minimally invasive surgery, industrial inspection, and more generally any scenario that requires manipulation within highly unstructured, confined environments, where traditional rigid-link robotic arms are not suitable for use. This course introduces students to fundamental topics in continuum robot design, modeling, and control. The course culminates in the development of a continuum robot simulator, where students apply the concepts learned in the classroom. Continuum robot platforms will also be available for laboratory/experimental work. **Prerequisites:** RBE 501 and 502 or equivalent courses.

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. Calculate the forward and inverse kinematics of continuum robotic arms.
2. Calculate the forward and inverse velocity kinematics of continuum robotic arms.
3. Derive the equations of motion (dynamics) of continuum robotic arms.
4. Measure the forces and deflections acting on a continuum robot.
5. Generate continuum robot designs that are optimal for a specific application.

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

- **Course Format:** Classroom sessions will be held in person.
- **Communication**:
  - **With the instructor/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**: 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.
- **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.

GROUND RULES

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

- **Assignments and grading:**
  - **Homework:** Homework consists of MATLAB-based problem sets. There will be a total of four homework assignments throughout the semester.
  - **Homework submission policy**: To provide as much flexibility as possible during these uncertain times, there will be two deadlines for homework assignments:
    1. *Soft deadlines*: Submitting by the soft deadline will trigger a 20% bonus on the total score for the assignment. Furthermore, 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.
    2. *Hard deadlines*: Hard deadlines will be exactly one week after the soft 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.
  - **Project:** These are practical team-based projects where students deploy the techniques learned in the classroom. These assignments are conducted in teams of 3-4 people.
  - **Grading breakdown:** The final grade for the course will be determined as follows:
    - Homework assignments: 40%
    - Project: 60%
  - **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 one week of the return of the graded assignment.
- **Attendance and participation:** attendance and active participation in lectures are strongly encouraged.
- **Academic Integrity Policy:**
  Rule of thumb: ***Any work 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
- **Students are encouraged to use campus support services**, which include the Academic Resources Center, the Writing Center and MASH (Math and Science Help).

COURSE SCHEDULE (TENTATIVE)

Week	Topic
1	Course Introduction Taxonomy of Continuum Robots Topics in Continuum Robotics research
2	Kinematics of Continuum Robots • Models based on constant curvature (Webster, 2010) • Robot-dependent vs. robot-independent kinematics (Webster, 2010) • Mechanics-based models (misc. papers)
3	Differential Kinematics of Continuum Robots • Robot-dependent vs. robot-independent Jacobian (Webster, 2010) • Derivation of the robot-independent Jacobian (Webster, 2010) • Case study: robot-dependent Jacobian for concentric tube robots (Webster, 2010)
4	Dynamics of Continuum Robots • Cosserat Rod Modeling (Rucker, 2019) • Elastic Instability (Gilbert, 2017)
5	Sensing for Continuum Robots • Review of sensing modalities for continuum robots • Sensor selection and placement (Mahoney, 2018)
6	Design Optimization of Continuum Robots • Kinematic design optimization (Burgner-Kahrs, 2015) • Case study: tube selection for concentric tube robots (Burgner-Kahrs, 2015)
7	Guest Lecture: Latest Research Results

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	Proj	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**		