ECE4560 - Introduction to Automation and Robotics (4-3-3)

School of Electrical and Computer Engineering
Georgia Institute of Technology

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Inquiry Room:	TSRB 442	*Inquiry Room:*	van Leer E265
Inquiry Hours:	Tuesday 1:00PM - 2:00PM Friday 10:00AM - 11:00AM	*Inquiry Hours:*	Monday 4:00PM - 6:00PM Friday 4:00PM - 6:00PM

Laboratory:	VL E265 (overflow: VL C257)
Lab Hours:	Open Lab from 8AM to 8PM (requires Card Access after)
Prerequisite:	ECE 3085/3084 or ECE3550
Course Book:	Craig, J.J. Introduction to Robotics: Mechanics and Control, 3rd Ed. Purchase not required.
Optional Refs:	Murray, Li, and Sastry. A Mathematical Introduction to Robotic Manipulation. Lynch, and Park. Modern Robotics: Mechanics, Planning, and Control. Spong, Hutchinson, Vidyasagar. Robot Modeling and Control. 3rd Edition. Additional eBooks to be noted elsewhere.

Catalogue Description: Fundamental disciplines of modern robotics: mechanics, control, and computing. Analysis, design, and control of mobile robots and manipulators. Course may contain team projects and hands-on labs.

Scope and Goals: The goal of the course is to provide you with the knowledge to analyze and understand robotic manipulators. Consequently the course will cover elements of theoretical and applied kinematics, which deal with the mathematical analysis and synthesis of mechanical manipulators.

At the termination of the class, you should be able to:

- analyze and mathematically describe a given manipulator,
- understand said manipulator's operational limits,
- create design proposals for a manipulator given its specifications,
- confidently read the kinematics and robotics literature, and possibly
- understand some of the programmatic issues related to serial manipulators.
- potentially pursue and demonstrate mastery in an area of robotics of your choosing.

Topic Outline: The course is broken up into two segments covering the following topics:

1. Mathematics and Modeling.
   - Coordinate representation of manipulators
   - Homogeneous coordinates and representation of orientation
   - Lie groups and Lie algebras, $\exp$ and $\ln$
   - Body versus spatial reference frames.
2. Kinematics
   - Forward kinematics
   - Workspace analysis
   - Inverse kinematics
   - Manipulator velocities and Jacobian
   - Task planning
3. Dynamics
   - A primer on Euler-Lagrange equations, Lagrangian mechanics
   - Position/Torque control

Course Mechanics and Grading: The course meets two times a week, TuTh 5:00-6:15PM in Klaus 2447. Being a laboratory course, each student must identify a lab experience. Students may either follow along with the standard manipulator (Robot Arm) project, choose an alternative platform (Mobile Robot or Biped), or may identify a suitable custom project. For the pre-existing projects, working in pairs is acceptable, but each student must submit their own solution. The standard manipulator project involves interfacing and controlling small manipulators. The alternative platforms include (1) controlling a mobile robot and (2) synthesizing a walking gait for a planar bipedal robot. The custom version may involve a group effort towards a project outlined by the instructor and refined with the group. It is up to the group to sub-divide their tasks and report the breakdown of effort.

The course grading criteria consist of the following components whose percentage of the total grade calculation is also given,

	Homework	Lab	Midterm	Final
Percent of Final Grade	40%	20%	20%	20%

where the contributions are based on total points per category (e.g., total points for homework).

Lab Projects. When considering which lab project to choose, please consider the following factors: the alignment of the project with the lecture material, the availability of actual solutions (in some cases, there are none), and the amount of external study necessary. Which lab track to elect will occur within the first three weeks of class. All projects will be required to present their project to the class during the last week of class, as well as submit a final report describing their project and its goals, plus some of their efforts towards realizing the goals. It is anticipated that the project-based trajectory might be more challenging than the standard trajectory (robot arm) due to the exploratory nature of the project. There will be some guidance by a group advisor to mitigate the difficulty.

Any written portion of the lab assignment always needs to be turned in with the homework. Late written submissions will be deducted according to the homework policy. All lab demonstrations are expected to be done by a certain date after the submission of the lab assignment, based on when inquiry hours are held. Late demonstrations will automatically lead to a 50% deduction on the lab demonstration point value. There is no expiration date on when demonstrations can be given once they are late; the deduction will remain constant, however, unless agreed upon in advance.

Homeworks. The homeworks are intended to reinforce the topics presented in class. I will typically make an effort to be available for a short period after class for any questions that may arise. You should also feel free to e-mail me if homework statements are unclear or to set up an alternative time to meet, however please be sure to include the string "ECE4560" in the subject heading. While collaboration is encouraged regarding the homework material, all work to be turned in is expected to be individually completed. It is presumed that we are all operating under the Georgia Tech Honor Code.

The agreed upon due date for the weekly homeworks is Thursday (10pm). On Canvas, I give a two hour grace period, so the homeworks can be turned in up until midnight on Thursday. All material should be submitted virtually via Canvas.

Extensions. All students are automatically given three days for extensions. These days can be broken up in any way. For example, three assignments can be handed in one day late each, or one assignment can be handed in three days late, or any other combination.

Once your three extension days have been used, homeworks can be submitted up to 24 hours late, without request, for a 10% penalty. If there will be a delay beyond 24 hours, then please contact me to negotiate a submission time, otherwise there will be a sliding scale for each additional 24 hour period. No matter what happens, do submit when you can so that the maximal credit possible can be assigned. Once the solutions are posted, late homework will not be accepted. Late lab submissions are acceptable when they have no corresponding solutions.

For any other extensions, or unusual circumstances, please contact me.

Programming. The course will require programming the learned mathematics into Matlab. Anyone wishing to utilize other platforms may do so and is more or less on their own; I am willing to provide help to a limited degree. If you are unfamiliar with Matlab, there are many sources of documentation and primers online.

For those choosing to work with the manipulator, Matlab will be the only option provided. Likewise, the bipedal robot project will involve Matlab plus some additional libraries that can be compiled to run on Windows, MacOS, and Linux. The Turtlebot Mobile Robot lab thread will involve the Robot Operating System (ROS) and python running on the Linux operating system.

Course Schedule (subject to change):

Course Schedule			
Week	**Date**	**Lecture**	**Assignment Due**
1	August 20	Syllabus + Introduction	
	August 22	1. Planar Kinematics	
2	August 27	2. Coordinates	
	August 29	3. Transformations	HW 1
3	September 3 (Guest)	Guest Lecture on Manipulation Research	
	September 5	4. Lie Groups	HW 2
4	September 10	5. Rigid Body Motion	
	September 12	6. Velocities	HW 3
5	September 17	7. Body Velocity	
	September 19	8. Spatial Velocity	HW 4
6	September 24	9. Exp. Coords. for Rotation	
	September 26	10. Exp. Coords. for Rigid Motion	HW 5
7	October 1	– Midterm Exam –	
	October 3	11. Manipulators & Manipulator Analysis	
8	October 8	12. Forward Kinematics	
	October 10	13. Inverse Kinematics 1	HW 6
9	October 15	– Fall Break –	
	October 17	14. Inverse Kinematics 2	HW 7
10	October 22	15. Manipulator Jacobian	
	October 24	16. Product of Lie Groups + Exponentials	HW 8
11	October 29	17. Manipulator Types	
	October 31	18.Inverting the Manipulator Jacobian	HW 9
12	November 5	19. Trajectory Design 1	
	November 7	20. Trajectory Design 2	HW 10
13	November 12	21. Trajectory Design 3	
	November 14	22. Dynamics of Manipulators	
14	November 19	23. Primer on Control	
	November 21	Group Projects 1	Project Reports Due
15	November 26	Group Projects 2	
	November 28	– November Break –	
16	December 3	Review	
	December 5-12	– Final Exam (Date TBD) –	