Course title: **CSCI 4/6525 Autonomous Robotics: Manipulation**

Course description: This course aims to introduce students to the core principles necessary to program robots for autonomous operation in dynamic, (typically) human-centric environments. This course is trans-disciplinary across Engineering: it covers concepts from Computer Science (reinforcement learning, perception), Mechanical Engineering (kinematics, dynamics), and Electrical Engineering (control theory).

Learning objectives: Students will gain the skills necessary to program robots to perform manipulation tasks autonomously. By the end of the course, students will understand both technical concepts—kinematics, dynamics, planning, control theory, etc.—and practical considerations—dynamic environments, uncertainty, and robust operation.

Pre-requisites/co-requisites: Single-variable calculus is required.

Number of credit hours: 3

Textbooks (required):
J. Craig. *Introduction to Robotics: Mechanics and Control, 3rd ed.* Prentice Hall, 2004.

Textbooks (from which reading material will be made freely available as warranted):
1. P. Corke. *Robotics, Vision, and Control: Fundamental Algorithms in MATLAB*. Springer, 2011.
2. S. LaValle. *Planning Algorithms*. Cambridge University Press, 2006.
3. S. Thrun, W. Burgard, and D. Fox. *Probabilistic Robotics.* MIT Press, 2005.
4. L. Sciavicco and B. Siciliano. *Modeling and Control of Robotic Manipulators, 2nd. ed.* Springer, 2000.
5. H. Choset, K. Lynch, S. Hutchinson, G. Kantor, W. Burgard, L. Kavraki and S. Thrun. *Principles of Robot Motion: Theory, Algorithms, and Implementation.* MIT Press, 2005.

Software:
We will use the following software in this course. Please install it or find a place you can use it as soon as possible (speak with the instructor if you have difficulties finding a workstation with the capabilities to run any of the software):
• Gazebo (robot simulator), http://*gazebosim.org*
• Mathematica (GWU provides a site license for this)
• MATLAB (GWU provides a site license for this)

Schedule:

Lecture	Topic	Readings	Assignment
1	Feedback control		Double pendulum swing-up
2	Rigid body pose I		(none)
3	Rigid body pose II		

Lecture	Topic	Readings	Assignment
4	Pose concatenation and forward kinematics		Planar robot kinematics
5	Differential kinematics and inverse kinematics		(none)
6	Trajectory planning		Point-to-point motion
7	Time of flight sensing		Octree and RANSAC
8	Nonholonomic robots		Wall following and figure 8
9	Robot dynamics: Lagrangian		Double pendulum derivation
10	Robot dynamics: Newton-Euler		
11	Nonlinear control		Inverse dynamics control
12	Force control		Compliance task
13	Blob detection		
14	Kalman filtering		Robot tracking
15	**Midterm**		
16	Motion planning		Obstacle course
17	Reactive robotics and multi-robot systems		
18	Mixing planning and reactivity		Three layer architecture
19	Linear stability analysis		
20	Nonlinear stability analysis		TBA
21	Rigid body contact I		
22	Rigid body contact II		
23	Static stability		Support polygon
24	SLIP		Raibert hopper
25	Zero Moment Point		

Lecture	Topic	Readings	Assignment
26	LIPM		Balancing against perturbations
27	Capture points		
28	Dynamic programming and optimal control		

Student expectations:
This is an introductory course in robotic manipulation, which is a truly interdisciplinary subject. Few students have the background to learn all of this material with ease. ***In order to get the most out of this class, you must read the material before the lecture.***

Course objectives:
Students should be able to satisfy the following objectives by the conclusion of the course:
• Convert orientations between rotation matrices, unit quaternions, and Euler angles
• Convert kinematic quantities between frames
• Compute equations of motion for a robot
• Build and tune a PD controller
• Apply Value Iteration toward solving an Optimal Control problem
• Conduct a linear stability analysis of a dynamical system
• Conduct a nonlinear stability analysis of a dynamical system
• Compute contact forces for one or more rigid bodies in contact
• Implement the RRT Algorithm

Perception-specific objectives:
• Track moving color blobs using a Kalman filter
• Build an octree data structure to store point cloud samples
• Fit a plane to point cloud data using RANSAC

Robot manipulator-specific objectives:
• Compute the forward kinematics for a robot manipulator
• Compute the Jacobian matrix for a robot manipulator
• Compute inverse kinematics using RMRC algorithm, forward kinematics, and the Jacobian for a robot manipulator
• Perform the pick-and-place task with a manipulator robot
• Plan and execute a trajectory for a manipulator robot to reach a point in operational space
• Implement inverse dynamics control for a manipulator robot

Legged robot-specific objectives:

• Compute the support polygon of a standing or walking robot
• Compute the Zero Moment Point of a standing or walking robot
• Implement control of a hopping robot using SLIP (spring loaded inverted pendulum)
• Balance a biped using the linear inverted pendulum model (LIPM)
• Compute a capture point for a robot

Performance evaluation (**4525**)*:*
Undergraduate student grades will be derived from *Gazebo*-based assignments (80%) and exams (20%). *Undergraduates can do a project instead of taking the final at their discretion*.

Performance evaluation (**6525**)*:*
Graduate student grades will be derived from Gazebo-based assignments (50%), exams (30%), and a student selected project (20%).

Assignments are due exactly two weeks after their date of assignment.

Example projects:
• Writing a joystick controller for driving the R. Links quadruped
• Designing a programming language for controlling legged robots
• Keeping a person from falling using the PR2 robot

Grade curving:
Grades will be only be curved at the end of the course and with the instructor's discretion (*generally based on attendance and class participation)*.