

Course Description: This course covers the algorithms and conventions used for modeling and controlling articulated robotic systems such as robot arms. In the first half of the course, kinematic and dynamic models of robot arm motion are developed. In the second half of the course, algorithms for designing robot trajectories and controllers are introduced. The course also has a laboratory component, where robot trajectory planning, kinematic and dynamic modeling and control strategies are demonstrated.

Instructor: Prof. Stephen L. Smith (stephen.smith@uwaterloo.ca; Office: EIT 3108).

Course Objectives: At the end of the course you should be able to:

- Formulate the Denavit-Hartenberg transformation matrices for any serial-link manipulator
- Compute the forward and inverse kinematics of any serial-link manipulator
- Write the equations of motion for a manipulator
- Design a point-to-point or via-point trajectory for a manipulator
- Develop and implement a variety of controllers for implementing joint space or task space control for any serial-link manipulator

Course Prerequisites: ECE 380 or equivalent, or permission of the instructor.

Course Outline: Homogeneous transformations. Kinematics and inverse kinematics. Denavit-Hartenberg convention. Jacobians and velocity transformations. Dynamics. Path planning. Nonlinear control. Compliance and force control.

Week	Lecture Topic
1	Introduction and Course Overview
2	Homogeneous transformations: Rotations, translations, forward and inverse homogeneous transformations, skew symmetric matrices, time-varying transformations
3	Forward kinematics: Denavit-Hartenberg convention for frame assignment, examples
4	Inverse Kinematics
5	Differential Kinematics: manipulator Jacobian, derivation and interpretation
6	Differential Kinematics: singularities: causes, effects and interpretation, examples
7	Dynamics: Review of basic free-body diagrams, moments of inertia. Manipulator kinetic and potential energies, Euler-Lagrange derivation of equations of motion
8	Dynamics: Newton-Euler derivation, Examples
9	Path Planning: Point-to-point, linear interpolation, blending, splines, via points
10	Control: Independent joint control, computed-torque, feed forward control, joint space control, inverse dynamics
11	Control: Operational space control, force & hybrid control, interaction and constraints
12	Control: Interaction and Constraints

Textbook: The required text for the course is

M. W. Spong, S. Hutchinson and M. Vidyasagar, *Robot Modeling and Control*, Wiley, 2005. ISBN: 978-0-471-64990-8.

Grading: The course grade will be based on a midterm examination, lab assignments, and a final examination, which will be held during the Official Examination Schedule. The breakdown is as follows:

- Lab Assignments: 30%
- Midterm Examination: 20%
- Final Exam: 50%

There will be 4 lab assignments each contributing equally to the final grade. Detailed information about the lab can be found on the lab website: <http://www.ece.uwaterloo.ca/~lab486>.

General University of Waterloo Guidelines:

Academic Integrity: In order to maintain a culture of academic integrity, members of the University of Waterloo community are expected to promote honesty, trust, fairness, respect and responsibility. Check <http://www.uwaterloo.ca/academicintegrity/> for more information.

Grievance: A student who believes that a decision affecting some aspect of his/her university life has been unfair or unreasonable may have grounds for initiating a grievance. Read Policy 70, Student Petitions and Grievances, Section 4, <http://www.adm.uwaterloo.ca/infosec/Policies/policy70.htm>.

When in doubt please be certain to contact the departments administrative assistant who will provide further assistance.

Discipline: A student is expected to know what constitutes academic integrity—check <http://www.uwaterloo.ca/academicintegrity/> to avoid committing an academic offence, and to take responsibility for his/her actions. A student who is unsure whether an action constitutes an offence, or who needs help in learning how to avoid offences (e.g., plagiarism, cheating) or about rules for group work/collaboration should seek guidance from the course instructor, academic advisor, or the undergraduate Associate Dean. For information on categories of offences and types of penalties, students should refer to Policy 71, Student Discipline, <http://www.adm.uwaterloo.ca/infosec/Policies/policy71.htm>.

For typical penalties check Guidelines for the Assessment of Penalties, <http://www.adm.uwaterloo.ca/infosec/guidelines/penaltyguidelines.htm>.

Appeals: A decision made or penalty imposed under Policy 70 (Student Petitions and Grievances) (other than a petition) or Policy 71 (Student Discipline) may be appealed if there is a ground. A student who believes he/she has a ground for an appeal should refer to Policy 72 (Student Appeals) <http://www.adm.uwaterloo.ca/infosec/Policies/policy72.htm>.

Note for Students with Disabilities: The Office for Persons with Disabilities (OPD), located in Needles Hall, Room 1132, collaborates with all academic departments to arrange appropriate accommodations for students with disabilities without compromising the academic integrity of the curriculum. If you require academic accommodations to lessen the impact of your disability, please register with the OPD at the beginning of each academic term.