CLEVELAND STATE UNIVERSITY
Mechanical Engineering Department
Electrical and Computer Engineering Department

# MCE/EEC 647/747: Robot Dynamics and Control

**Catalog Description:** MCE/EEC/647/747 (4-0-4) Robot Dynamics and Control. *Prerequisites: MCE441/ 541 or EEC510 or exposure to undergraduate controls, with instructor consent. Study of robotic manipulator systems, with strong emphasis on dynamics and control. Energy-based nonlinear models. Motion control using PD, inverse dynamics and passivity. Force control. Geometric nonlinear control applied to robotic manipulators.*

**Textbook:** -Robot Modeling and Control by Spong, Hutchinson and Vidyasagar, 2006

**Instructor:** H. Richter, Associate Professor, Mechanical Engineering

**OFFICE HOURS, SPRING 2012: Mondays, 2PM to 4:00PM (walk-in) and Wednesdays , 2:00 to 4:00 PM (prior appointment). Other times can also be arranged by appointment.**

**Course Objectives:** This course introduces essential concepts and analytical tools to understand common robotic manipulators and associated control systems. The course will enable students to:

1. Obtain mathematical models and implement computer simulations of various robotic manipulator configurations.
2. Select an appropriate control strategy and design stable controllers using analytical tools.
3. Implement computer simulations of closed-loop control systems for robotic manipulators and perform tuning and simulation studies.
4. Use analytical and simulation techniques to design a controller, followed by real-time deployment to a PUMA manipulator available in the laboratory.

**Topics:**

1. Introduction. Common manipulator configurations. Task space, configuration space and state space.
2. Review of linear algebra: linear transformations, basis and dimension. Subspaces and rank. Useful Matlab commands. Application to forward and inverse kinematic problems.
3. Robot dynamic models by energy methods (Euler-Lagrange)
4. Nonlinear dynamical systems. Lyapunov stability theory.
5. Robot motion control by PD, inverse dynamics and passivity methods.
6. Impedance-based force control.
7. Introduction to geometric nonlinear control: feedback linearization. Backstepping. Differential flatness (if time permits)

**Evaluation:**
Homework will be regularly assigned (30%). There will be two midterm exams, with a combined weight of 40%. One of these exams will involve a simple laboratory experience with the available manipulators. A final project will be assigned, with a weight of 30%. As part of the final project, students will implement a real-time controller on the PUMA manipulator.

Computer simulation tools will be used extensively throughout the course: Matlab/Simulink and/or Scilab/Scicos. Students are expected to be proficient in these tools. In addition a Mitsubishi RM-501 manipulator and a fully-instrumented PUMA arm will be available for practical demonstrations and projetcs.

**Note regarding evaluation of MCE/EEC647 and MCE/EEC747:**
Although the course contents are the same for 647 and 747, the latter course will involve additional assignments and separate exam questions. Specifically:
1. The projects and reporting requirements will be the same for 647 and 747.
2. The midterm and final exams will contain one or more questions to be solved by 747 students only. The total number of questions in a given exam will be the same for 747 and 647.
3. 747 students will be required to read, summarize and reproduce the simulation results of a research article provided by the instructor.

| **Topics** | **Hours** |
|---|---|
| 1. Introduction to robotic manipulators and their applications. Outline of robot motion planning and control problems. Scope of course. | 2 |
| 2. Review of linear algebra in the context of robotics. Rotational transformations | 4 |
| 3. Overview of forward and inverse kinematics problems. | 6 |
| 4. Decoupled control. Feedforward, feedback and combined approaches. | |
| 5. Energy-based robot dynamic models. Skew-symmetry and passivity. | 8 |
| 6. First Midterm Exam including laboratory | 4 |
| 7. Nonlinear dynamical systems. Introduction to Lyapunov stability theory. LaSalle's theorem. Quadratic Lyapunov functions. Instability results. | 8 |
| 8. MIMO control of manipulators: PD, inverse dynamics, passivity and adaptive schemes. | 8 |
| 9. Force control. Impedance methods. | 6 |
| 10. Second Midterm Exam | 2 |
| 11. Geometric methods in nonlinear control. | 6 |
| 12. Laboratory work, final project | 8 |

Total instructional/in class-exam hours, Spring 10 semester 62

Prepared by: Dr. Hanz Richter January , 2012