Syllabus

Robo4x Locomotion Engineering

Instructor: Dr. Daniel E. Koditschek

Course Overview:

How do robots climb stairs, traverse shifting sand and navigate through hilly and rocky terrain? This course, part of the Robotics MicroMasters program, will teach you how to think about complex mobility challenges that arise when robots are deployed in unstructured human and natural environments. You will learn how to develop dynamic models of legged machines suitable for designing controllers that achieve robust, stable steady state locomotion on complex terrain. We will cover classical linear and nonlinear robot dynamics models and then combine them in more complicated hybrid nonlinear systems models that capture the crucial role of making and breaking ground contact characteristic of legged systems. We will use these models for the design and analysis of locomotion controllers that target successively more complicated, higher degree of freedom legged systems. We will use the problem of hopping in place as the baseline behavior, then add stepping control to regulate fore-aft speed, and end the course with projects modeling the control of actual physical running machines. You will learn how to design and program the sequence of energetic interactions that must occur between sensors and mechanical actuators in order to ensure stable mobility. We will expose you to underlying and still actively developing concepts, while providing you with practical examples and projects.

In sum,this course will present fundamental theory and computational methods that enable you to model and control a legged robot's dynamical gait. Using MATLAB, you will apply what you have learned through a series of projects involving successively more realistic (and, at the end, actual, real-world) robotic systems.

Prerequisites:

- Good understanding of multivariable calculus and prior exposure to linear algebra and ordinary differential equations.
- We will be making specific use of the kinematics and rigid body dynamics ideas developed in the ROBO3x, certain linear algebra techniques in the ROBO1x, and various ideas and techniques presented in the ROBO2x.

Course Outline:

Week 1 - Big-Picture Motivation: overview of the course; introduction to the nature of locomotion in animals and machines emphasizing the importance of bioinspiration in robotics with particular focus on the problems of legged mobility and the integrated role of physical and mathematical foundations.
Week 2 – A Linear Time Invariant Mechanical System: using the example of a 1 DoF prismatic kinematic chain in gravity to review basic dynamical systems concepts (e.g., flows and change of coordinates) and make the connection to physical notions of energy and power.
Week 3 - A Nonlinear Time Invariant Mechanical System: using the example of a 1 DoF revolute kinematic chain in gravity to review more advanced dynamical systems concepts (e.g., stable and unstable equilibrium states) and make the connection to physical notions of energy conservation and dissipation.
Week 4 – Project #1: A Brachiating Robot – investigating the problem of swinging along from branch to branch with a 2 DoF (all revolute) underactuated machine to expose the underlying complexity of locomotory dynamics; developing a simple controller that forces the erstwhile chaotic machine to "anchor" the tractable 1 DoF LTI "template" from Week 2.
Week 5 – Qualitative Theory of Dynamical Systems: obtaining mathematically rigorous guarantees of stability by recourse computationally effective analysis via Linearization and Lyapunov functions.
Week 6 – First Locomotion Model: modeling the continuous time components of Raibert's vertical hopping machine using all the notions of classical applied dynamical systems theory from the preceding weeks.
Week 7 – A Vertical Hopping Controller: introducing the concepts of a hybrid dynamical system and Poincare' return map in 1 DoF to show how the Raibert Vertical Hopping algorithm stabilizes hopping height.
Week 8 – Project #2: From Bouncing Ball to Stable Hopper – building up a simulation environment for numerical exploration of the Raibert Vertical Controller.
Week 9 – The Spring Loaded Inverted Pendulum (SLIP): introducing the prototype of bioinspired running models, a 2 DoF nonlinear hybrid dynamical system; crcumventing the fundamental problem of non-integrable dynamics by recourse to central force approximation and developing the consequent closed form expressions for the flow.
Week 10 – Stepping Control of Fore-aft Speed: using the SLIP approximation from Week 9 to build a complete hybrid systems model of bioinspired saggital plane running taking the form of an apex return map; using the return map to analyze and compare the Raibert stepping control with a more aggressive "inverse dynamics" variant.
Week 11 – Project #3: Anchoring SLIP in Multi-Jointed Mechanisms – numerical investigation of how the combined SLIP vertical and fore-aft designs can be re-used to control saggital plane running in increasingly complicated legged mechanisms.

Week 12 – Project #4: A Running Controller for the Jerboa Robot – extending the methods developed in Project #3 to apply to a sagittal plane view of the Jerboa robot, a physical bipedal robot under active development in our Lab.

Verified Learner- Earning a Certificate

To earn a verified certificate for this course, you need to be enrolled as part of the verified track, complete identity verification and earn a passing grade. If you are auditing the course, you will not receive a certificate. **You must be registered as a verified learner before the proctored midterm exam to earn a certificate.** Please note that verification is required for the proctored assessments and missing the verification deadline will make you ineligible for a certificate. Register for the verified certificate here.

Grading

This course is pass/fail only. You will not receive a letter grade on your certificate.

Passing Grade: You must score **60%** or above to pass the course.

Showing Answers: After completing a quiz question or using up all of the attempts, the option to show the answer will appear. This option is not available for homework assignments, labs, projects or tests.

Weights of Graded Assessments:

Quizzes (5%): There will be 27 total quizzes and your lowest 2 scores will be dropped.

Labs (15%): There will be 7 lab assignments and all will count.

Projects (35%): There will be 4 projects and all will count.

Midterm (20%): There is one midterm in the course after week 6. You must be enrolled in the verified track to take the midterm!

Final (25%): There is one final exam in the course after week 12. You must be enrolled in the verified track to take the final exam!

Effort

We expect this course will take you 8-10 hrs per week to complete.

Communication

Discussion Forum: We will be communicating with you through the discussion forum on a daily basis. Please reach out to us through the discussion forum with any questions about the course content. Please allow 24 hours to receive a response from a TA or an instructor. Also, all communication on the discussion forum must follow the edX Honor Code. Never post code or solutions to assignments on the discussion forum.

Weekly Emails: We will be sending you course updates and interesting information about the field of robotics weekly.

Live Chat Sessions: If you are part of the verified track, we will be offering live chat sessions where learners can speak directly with the TAs. Details will be sent in the weekly emails.

Academic Integrity

Definitions of Academic Dishonesty:
Activities that have the effect or intention of interfering with education, pursuit of knowledge or fair evaluation of a student's performance are prohibited. Examples of such activities include but are not limited to the following definitions:

- Cheating: Using or attempting to use unauthorized assistance, material, or study aids in examinations or other academic work.
- Plagiarism: Using the ideas, data, or language of another without specific or proper acknowledgment. Example: using another person's work and using it to submit an assignment/project/lab work, cloning someone else's ideas without attribution etc.
- Unfair Advantage: Attempting to gain unauthorized advantage over fellow learners in an academic exercise. Example: gaining or providing unauthorized access to examination materials, etc.

edX Honor Code Pledge

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- Complete all tests and assignments on my own, unless collaboration on an assignment is explicitly permitted.
- Maintain only one user account and not let anyone else use my username and/or password.
- Not engage in any activity that would dishonestly improve my results, or improve or hurt the results of others.
- **Not post answers to problems that are being used to assess student performance.**

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