Instructional Improvement Grant Application: Multi-Media Courseware in Robotics

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Abstract ▪ We are requesting funds to support the development of both simulation exercises and real-world hardware to enhance learning in an otherwise lecture-based course in robotics. By creating exciting and challenging "hands-on" laboratory experiences where students can experiment and create, we anticipate both increased student interest and improved retention of fundamental concepts in robot dynamics and control theory.

Introduction ▪ Robotics is both a growing field of interest among engineering students in ECE, ME and CS and a growing industry in society, likely to hire an increasing number of graduates in the coming years. Toward satisfying these demands, the Department of Electrical and Computer Engineering is providing a new senior elective course entitled "Robot Dynamics and Control", to be offered for the first time in Winter 2011 as a special elective, under the temporary numbering ECE194.

Content for the course will be developed over the summer of 2010. This ECE-staffed course complements three related classes currently taught in ME and CS, as it studies important, theoretical concepts in the dynamics and control of robots and other electromechanical devices that is currently absent from the engineering curriculum at UCSB. Briefly, the new course studies the inherent nonlinear dynamics of robot systems and the use of control in modifying these dynamics to meet design criteria. More detail is given in the "Course Goals and Content" section ahead, and an overview of the broader plan to revise the robotics curriculum at UCSB may be found online here:

http://motion.me.ucsb.edu/robotics-curriculum/

We anticipate that providing appropriate hands-on learning experiences in this new class will aid tremendously in sparking enthusiasm, in developing intuition for robotics and control, and in inspiring creative problem solving. To develop such tools, we propose (1) to develop simulations of dynamic robot systems that mimic real robot systems, that students can download and run and explore on their own time schedule, without the time, space and safety constraints of a laboratory setting and (2) to purchase a limited number of real robots, providing an important (yet affordable) real-world component.

Background and Goals ▪ We anticipate that "Robot Dynamics and Control" will be a popular senior elective, with initial enrollment expected to match our planned capacity of approximately 40 students a quarter and with student participation spanning the ECE, ME and CS departments. Although this will primarily be a lecture-style course, hands-on laboratory experiences will play a key role in developing intuition and interest. A significant challenge for us is to provide such experiences in a cost-effective and flexible way, to maximize the long-term benefits of curriculum development.

The new course content will strongly complement the material taught in Prof. Francesco Bullo's robotics course, ME170A / ECE181A. However, there is no dependency between the two courses: either course may be taken alone. Robot planning essentially consists of two fundamental tasks:

> **Kinematics** – Planning motions, without regard for the cause of the motion.
> **Dynamics** – Determining the differential relationships causing motion.

Kinematics involves problems such as determining the geometric relationships between the joint angles in a robot arm and the resulting *position* of its hand in space, or determining the shortest path to get through a cluttered environment. *Topics such as these are covered in Prof. Bullo's course.*

Dynamics involves problems such as determining the differential relationships between the torques and forces at the joints in a robot arm and the resulting *speed* of its hand, or determining how much force a robot is applying as it manipulates an object to move it. *These topics are covered in Prof. Byl's course.*

We note there are also two additional engineering courses at UCSB relating to robotics. One (ME170C/ECE181C) involves the practical implementation of programming a microcontroller to control a robot, and the other (CS/ECE181B) studies computer vision, which has general applicability in the field of robotics. There are no order dependencies among any of the courses, although we anticipate each course may spark interest in the other, complementary topics.

Course Goals and Content ▪ This section describes what will be taught and how the courseware developed using Instructional Improvement Program grant funds would enhance instruction. A few particular examples of class modules are provided. Most of the laboratory projects will involve online simulations and downloadable MATLAB code, but we believe it is vital to include at least one real-world system. For this purpose, we have selected the inexpensive "Rovio" wifi-enabled robot, pictured in Figure 1.

Example 1: A two-link, underactuated robot. The "pendubot" and the "acrobot" are two examples of a two-link pendulum mechanism with a single actuator. Because each system has more degrees of freedom (2 links that can rotate) than actuators (1 motor, at either the first *or* the second link, only), it is an *underactuated* system. Despite this, however, it is possible to develop control algorithms for swing up and stabilization of this double-pendulum system into a vertical configuration. This example explores nonlinear dynamics and control. There are a variety of control approaches that can stabilize this system, and it is useful and interesting to compare both the performance and the power requirements of each one.

Example 2: Motion control of a rolling robot. The Rovio has an intriguing wheel design, which allows it to move very differently that an automobile: the omni-directional wheels allow it to move sideways or to turn in place! This *should* make it a cinch to move anywhere you like. However, the actually rolling dynamics are very nonlinear, and they are not controlled well on the robot, so, for example, it will not go in a straight line when moving sideways. As robotics engineers, we can design our own control algorithms that perform much better. Students will do so on both a simulation of the robot and on the true device. The robot may roll differently on different surfaces (slick tile versus high-traction carpet). A well-designed controller will compensate for this, so the motions of the robot appear the same, regardless of the perturbations caused by the changing wheel traction. Other control tasks for the Rovio include "follow the leader", kicking a soccer ball accurately, and tracking an object with the onboard webcam.

Other examples: Tentatively, a total of 8 simulation modules is planned. Except for the Rovio project – which will take 3 weeks at the end of the quarter – each module will be completed in one week. In addition to the Rovio, project modules include: a two-legged walker, a multi-link (fully-actuated) robot arm, a flapping-wing robot, an propeller-driven undersea vehicle, a weightless satellite manipulating an object in space, a hopping robot, and either or both of the two-link underactuated pendulums (from Example 1).

Figure 1. The Rovio wifi-enable webcam robot. At left: The robot is docked at its power charging station and connected directly to a laptop, to set up wireless connectivity. At right: The robot is on the move! The navigation beacon is the ball-shaped object attached at the side of the docking station. The beacon projects two infrared spots onto the ceiling, which the robot uses to triangulate its position and orientation in a room.

Assessment ▪ We will coordinate with the Instructional Development staff to develop an evaluation process to assess the benefits of this work. Ideally, this should monitor both qualitative student enthusiasm for the subject and quantitative academic performance. We suggest the use of both mid-term and end-of-term surveys, thereby providing some feedback during the course of instruction and isolating the experiences with MATLAB simulations only from those at the end of the course involving the actual Rovio robot.

Quantifying performance is an important challenge. We tentatively propose developing a multiple choice section on both the midterm and final exams that is designed to gauge intuition about dynamics and control. For example, students may be given a set of differential equations (1,2,3…), a set of frequency responses (A,B,C,…) and a set of time responses (i,ii,iii,…) and asked to match each equation with both the appropriate frequency and appropriate time response. With this format, it is easy to develop a large variety of different, randomized system examples. Prof. Byl has found this to be a quick an effective way of gauging intuition in introductory courses in dynamics and control at MIT, where she has TA'd both sophomore and senior-level courses covering similar material.

We anticipate that students across ME, ECE and CS will have varying backgrounds in these fundamental concepts, so it may also be advisable to give a “not for credit” quiz at the beginning of the term, to benchmark student comprehension, as well. These are all tentative suggestions. We are enthusiastic about finding the most effective ways of assessing and improving the course content and look forward to engaging actively with Instructional Development in doing so.

Long-term Plans ▪ As mentioned, the creation of “Robot Dynamics and Control” is part of a larger effort within the ECE, ME and CS departments to reorganize the UCSB undergraduate curriculum in robotics. “Robot Dynamics and Control” has strong support from the ECE Department, as noted in the attached letter from our Department Chair, Jerry Gibson.

To facilitate maintenance and organization of the online modules and assignments, we hope to utilize the capabilities of *GauchoSpace* extensively. For example, we will post weekly lab projects and required MATLAB code that must be downloaded and modified in completing assignments, and we will collect a variety of uploaded student materials, including MATLAB code, figures and saved data files. We also hope to provide a wiki-style environment for students to ask questions, with TA or instructor responses that are visible to the entire class, and we hope to use anonymous surveys throughout the course to estimate the effort required for and value received from various assignments. In particular, because enrollment is aimed at ECE, ME and CS students, it will be important to ensure the assignments are not biased unfairly for or against any particular academic background. I hope the success of this class may also help in generating greater enthusiasm among engineering departments for the use of GauchoSpace.

Because most of the laboratory component consists of online MATLAB simulations, the overhead in content maintenance and the required staffing for the course should be much smaller than in a traditional lab class. Specifically, we expect one full-time TA will be sufficient. The one potentially fragile element in this plan is the Rovio itself. However, we have budgeted for extra robots, and we note that such robots are relatively cheap (and becoming cheaper over time).

We anticipate a significant long-term impact and believe that providing an exciting robotics program with (ideally) a publicly-visible internet “footprint” will directly increase the number and quality of undergraduate applicants in engineering at UCSB. This course will also be available for graduate enrollment, and I believe it will have a notable impact in graduate studies, as I often receive inquiries from graduate students about suggested robotics course at UCSB.

The long-term plan is to offer this course once per year. Each of the three currently-offered courses will be also offered once annually, likely with renumbering to allow the same numbers to be “cross-listed” across the ECE, ME and (optionally) CS departments, and with identifying letters that serve as a shorthand for the course nicknames and specifically do not imply chronological order or dependency. One such likely scenario is (in alphabetical order):

CS/ECE/ME 127D	Robot **Dynamics*** (ECE194 – to be offered Winter 2011)
CS/ECE/ME 127K	Robot **Kinematics** (now ME170 / ECE181A)
CS/ECE/ME 127L	Robot **Laboratory** (now ME170C / ECE181C)
CS/ECE/ME 127V	Robot **Vision** (now CS/ECE 181B)

* “Robot Dynamics” is the working nickname for the Robot Dynamics and Control course discussed throughout this proposal.

Budget and Work Plan

The proposed development team will consist of two graduate students, both working under the guidance of Prof. Katie Byl over the summer of 2010 (June 15 – Sep 17). A final proofing and debugging of materials will be done by Katie during Fall 2010, in preparation for the first course offering, in Winter 2011.

One student will be responsible for developing, testing and debugging the MATLAB simulation. Pat Terry is a great match for this. He has taken the core ECE undergraduate controls sequence and, due to his exceptional academic performance (GPA of 3.97), has been offered a graduate student TA fellowship for the upcoming (2010-2011) school year. Ideally, he may also be assigned to TA this course in its first offering, in Winter 2011.

The second student will design and test the controls interface to the robot. I hope to hire graduate student Marco Rodriguez-Saurez to work on this. Out of the box, the robot can be controlled by hand ("Joystick" style) with an on-screen GUI. For the purposes of the course, however, students must design an autonomous controller. The ultimate goal is to provide an intuitive and easy-to-use interface for students, where their own MATLAB code interfaces seamlessly with either a MATLAB robot *simulation* environment or with the *actual* robot itself. Achieving this, however, will require substantial programming over the coming summer in Java to create a fluid and appropriately debugged interface. I am currently working with three graduate students (including Marco) in an advanced controls class this quarter to examine the range of possible control tasks a Rovio can perform, and to explore the possibility of using a cell phone as a "Wii-controller" style interface. Marco will be required to do substantial additional work over the summer, however, to turn the Rovio into a workable platform for the class and to develop appropriate laboratory projects that can be posted as online assignments on GauchoSpace.

Budget details: We propose each of the 2 students will work for 12 out of the 14 weeks during the summer of 2010, at 40 hrs/wk for $15.53/hr, or:

2 students x 12 x 40 x $15.53 =	$14,908.80	Graduate Student Aid, summer 2010
Overhead @ 4.9% x above =	$730.53	
Total student labor costs =	**<u>$15,639.33</u>**	

We will also purchase several wifi-enabled robots and a wireless router. At present, we anticipate use of the "Rovio" wifi-enable three-wheeled robot, which is currently available with free shipping through Amazon for $139.99 each. To allow the robots to interact (for instance, to compete), I plan to use about 5 robots, but I am additionally budgeting for "backup" robots, anticipating an average of one broken robot per year, due to normal wear and tear.

10 Rovio robots x $139.99 =	$1,399.90	(Amazon.com price)
1 Cisco Linksys wireless router =	$83.99	(BestBuy price)
Total equipment costs =	**<u>$1,483.89</u>**	

Note on the wireless router: The computers students will use to send commands to the robot may be connected in any manner to the internet (wired or wireless UCSB internet access), and we anticipate using an ECE classroom with dedicated desktop computers. However, the robots themselves must communicate with the internet via wireless, so we will set up a dedicated wireless network. After discussion with Information Technology (Ken Dean) in the ECE Department, this solution seems to be most practical.

The total cost for both labor and equipment is: $15,639.33 + $1,483.89 = **<u>$17,123.22</u>**

Please contact me if you have any questions or concerns.

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