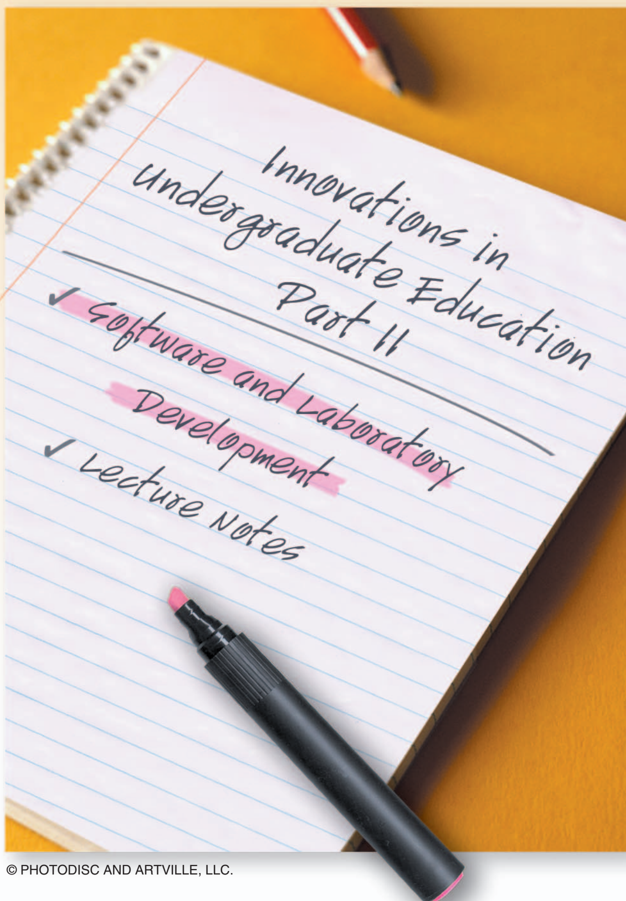
An Undergraduate Laboratory for Networked Digital Control Systems

Combining digital control with networks and information technology



By Dimitrios Hristu-Varsakelis and William S. Levine

Laboratory and project courses are well recognized for their educational value in any science-related discipline, including control and engineering, where the difference between classroom-based training and the real world is a core issue. The laboratory is often the only place where experimentation and exposure to new technologies occur within the typical four-year engineering curriculum. At the same time, however, laboratory courses are particularly difficult to run because they are by nature open-ended and require an enormous investment in equipment, as well as faculty and staff time. These concerns have led to the development of a new senior-level laboratory/project course at the University of Maryland, College Park, titled "Networked and Distributed Control Systems." The new course, now in its third year, is partially supported by an NSF research and curriculum development grant and brings together undergraduates from three engineering departments (electrical and computer, mechanical, and aerospace) with plans to include chemical, civil, and fire protection engineering in the near future.

The course combines digital control with networks and information technology. The course goals are to introduce students to emerging areas in systems theory, including topics in networked and distributed control systems; to leverage instructor time and increase productivity in laboratory classes while keeping student teams small; and to minimize costs by using highly adaptable general-purpose equipment.

Laboratory Description

The laboratory that hosts the course, shown in Figure 1 during a typical session, currently includes six stations. Each station is outfitted with a power supply and a pair of PCs, one of which hosts a Quanser data acquisition card

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and acts as the digital controller. Students at each station can connect any one of three different control experiments to their controller PC (there are a total of 18 plants available). All PCs run the real-time operating system RTLinux and are part of a common local network, so that an experiment at one station can be controlled from a PC at any other station (see Figure 2). In addition to enabling interesting new experiments, this capability adds to the redundancy of the hardware without additional costs.

Controller programming is done in MATLAB/Simulink so that the emphasis is on designing, testing, and evaluating controllers, as opposed to programming and debugging code. The lab's software environment (Simulinux-RT) allows a Simulink-based controller designed on one PC to be compiled and downloaded to any other "target" PC (presumably that to which a physical experiment is connected) at the click of a button. Establishing an all-digital controls laboratory has meant that controllers can be implemented on inexpensive computers and that sophisticated decision-making and nonlinearities are not much more difficult to implement than traditional proportional-integral differential (PID) designs.

The availability of a network means that the students and the instructor can operate and monitor experiments remotely. The network also turns the lab into a large distributed system and allows us to introduce ideas in multi-modal control, switched systems, and networked control with a minimum of effort. Besides bringing students in contact with some of the newer theory, this course attempts to introduce students to the complexities of modern control systems, which are often ignored during early controls education.

Two main points are emphasized with regard to network-based control. First, if a control system includes a network or other shared medium, then sensor and actuator signals might not be available simultaneously to the decision maker. It thus becomes necessary to consider the effects of transmission delays, scheduling, and quantization. Second, dynamical systems that were decoupled in the absence of communication constraints can potentially become coupled through their shared use of the network. Thus, the choice of communication policies significantly affects the problem of controller design as well as the controller's performance. At present, these ideas are introduced through an exercise in the simultaneous stabilization of two inverted pendula, which are located at two different stations in the lab, by remote controllers that must share a common wireline network. More sophisticated networks such as CAN and IEEE802.11 are planned for upcoming semesters.

Combination of Structured Experiments and Small Projects

We believe that it is difficult to overestimate the importance of projects as an educational tool. At the same time, most students require some degree of preparation before they can be successful at a project. Our course assumes minimal prior laboratory experience and thus guides students through a series of structured experiments for the first half of the semester before requiring them to undertake a project. The structured portion of

Figure 1. *The Maryland Controls Teaching Laboratory. Two of the six laboratory stations are shown here during a typical session. The course serves approximately 24 students, with enrollment and laboratory space expected to double in the next year.*

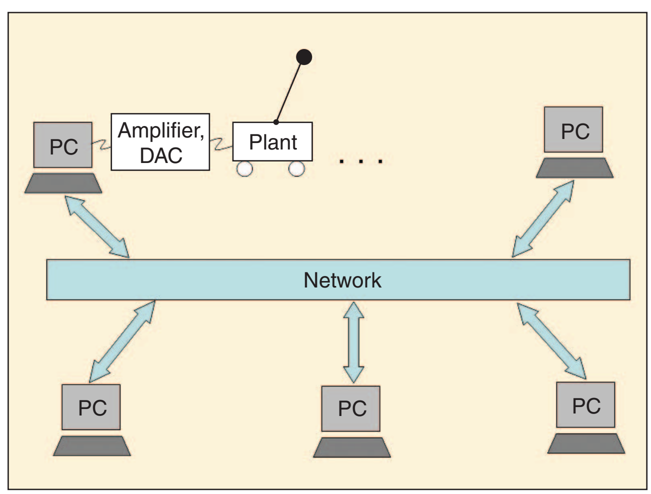

Figure 2. *Network infrastructure in the Maryland Controls Teaching Laboratory. Experiments are accessible from all stations. A controller implemented in one station can control experiments in more than one station, allowing students to explore control with limited communication.*

the course begins with an experiment in controlling single-input, single-output (SISO) systems with transport delay and ends with the design and implementation of a multi-input, multi-output (MIMO) controller that takes a pendulum from its stable position to its inverted position and stabilizes it there. The students are asked to create a controller that is multimodal, nonlinear (to perform the swing up), and includes an inherently nonlinear safety net that prevents the system from doing anything that might cause injury or damage.

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Projects are chosen to be small so that they can be completed in one semester. We have learned that it takes a few weeks for students to learn enough to be able to define a project. We ask for a brief proposal and explain that the project should be ambitious enough to have a 50% chance of success. We feel that it is important to allow projects to fail, provided that the students learn enough in the process. The previous year's failed projects often provide starting points for the current crop of students. As the semester develops, students acquire skills that are often critical to the success of their project but cannot be accessed within the typical lecture or laboratory class. These skills include management of the project, locating and ordering materials, and the difficulties of interconnecting disparate components.

Student Teams

Students in the course are organized in pairs. We have found that this approach fosters cooperation and helps avoid the uneven distribution of work that often occurs in larger teams. Because the course includes students from several departments, pairs are cross disciplinary, for example, one student from electrical engineering and another from mechanical engineering. This approach often has a positive effect on the team's ability to make progress and troubleshoot experiments. We have found that the electrical engineering students can sometimes help teach the theory, while their mechanical engineering or aeronautical engineering counterparts help teach experimental skills and physical intuition. Of course, the premise of the course is the importance of combining both categories of skills, while making "moments of clarity" a more frequent occurrence.

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