THE NEW MOTORS AND CONTROLS LABORATORY at HOWARD UNIVERSITY

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Abstract
A generous equipment donation from Moog Aerospace has enabled the Department of Electrical and Computer Engineering (ECE) at Howard University to develop a new motor and control laboratory using state-of-the-art industrial motor controls. Accordingly, a laboratory has been renovated and equipped with three-phase power to house the new workstations. The hardware for each of these workstations is mostly complete, but refinements are continuing on the human-machine interface, controls, and data acquisition system. The key hardware element of such capability is an embeddable dSpace digital signal processor (DSP) controller board that can be connected to various sensors and actuators, depending upon the system objectives. The workstations offer many possibilities for experimentation on motors and controls similar to those that students will encounter in the “the real world.” Moreover, laboratory experiments are being developed for the workstations. These experiments will supplement junior-and senior-level undergraduate lecture classes.

1 Background

In recent years there have been enormous financial pressures on engineering departments struggling to deliver to increased enrollments, unchanging budgets, and the need to maintain educational quality. As departments look for ways to cut costs, hands-on instructional laboratories, typically expensive to develop and maintain, are slowly being replaced with simulated experiments [1-3]. While simulations are an important component for teaching students about general system behavior, they cannot always account for all the details that must be considered in designing and analyzing a physical system in an interdisciplinary, team-oriented environment. Furthermore, a laboratory curriculum based on simulations alone would not adequately present problems that students may see in a physical laboratory nor provide adequate hands-on experience necessary for effective learning. The need to control real hardware, and not just simulations, is known to all who design and build real control systems. How this applies to control-systems education is emphasized in [4]. Modeling and simulation rarely capture the complete picture—physical system exposure is required; control experiments often focus attention on performance and implementation issues that are overlooked and difficult to capture in simulation; experiments can reveal whether or not assumptions made when making a control design are realistic; and experiments provide a way to identify control methods that seem to work under real-world conditions as well as those that clearly don't. This ultimate point leads to real learning. The instructional laboratories will expose students to conduct various practical experiments and also challenge them to examine cause and consequence relationships related to physical phenomena [5, 6]. Laboratory-based courses are typically conducted using software running on a host computer. Several educational programs [8-12] offer such laboratory-based courses, both traditional and online. A comparison of educational outcomes between in–person and remotely operated laboratories is presented in [13]. The lack of physical contact in the remotely operated laboratories with the experimental apparatus by the student may lead to a lack of experience with even simple tasks, such as connecting patch cables, and being versatile with connecting hardware components. Another article [14] promotes the control-systems laboratory at the University of Illinois at Urbana-Champaign. An appealing quality of this facility is that it is shared among several departments.

Undergraduate control-systems laboratory at Howard University had traditionally been accomplished via simulation, on one of the lab's digital computers using MATLAB and SIMULINK by MathWorks. Simulation using either method has limitations. One opportunity arising from the past experience is that we are free to start from scratch with its redesign, and when choosing the dynamic systems that would be the primary focus of experiment. We also fell that it would be of greater benefit to the students if we require that they learn to control many aspects of high performance motor drives. Then, the dynamics of only motor drive systems in the high power range and the low power range need be thoroughly understood; hence, more time may be devoted to studying how control-systems theory applies.

The experience of bringing a design from concept to working prototype is a valuable training for subsequent education and employment. Consequently, instructional laboratories are an important part of engineering education. In response, a new instructional laboratory is proposed for the design and implementation of several experiments demonstrating state-of-the-art control system for use in an undergraduate engineering education.

2 Laboratory for Experimental Teaching

One of the key objectives of this laboratory is to cover the experimental training in the electromechanical energy, industrial controls, and dSpace DSP control unit at various teaching stages. The instructional laboratory is planned to be used not only for hardware experiments but also for software, and dedicated to students with diverse levels of motor control and drives concepts. The activities that the laboratory expected to support can be classified as follows:

- Hardware: The student receives a considerable information of the operation of the dSpace DSP controller board which allows the student to learn the sequential interfaces between the host computer, the driving circuit, and the motor drive system. The student, thus, experiences the connection and use of different peripheral devices, such as pulse-width-modulated (PWM) inverters, transducers, serial interfaces, sensors, etc.

- Software: The student obtains good learning abilities in running programming peripheral devices such as A/D and D/A converters, serial communication devices, input-output interfaces. Rather than requiring that the student writes C-language code and interrupt-service routines, the student can use the dSpace DSP software tools with MATLAB/SIMULINK interface.

- System design: The student learns how to design and configure control systems especially adapted to electromechanical systems, industrial motor controls, and automation applications.

3 The New Instructional Laboratory

A year ago, Moog donated funding for an in-kind equipment gift to Howard. This gift was targeted specifically for ECE, with the ultimate goal of equipping a multi-disciplinary senior capstone design project laboratory in mechatronics. The ECE department chose to use the donation to develop a modern motors and controls laboratory. The Moog equipment was well suited for such a development. Since most laboratories have approximately 15 to 20 students per section, we decided to create 6 workstations, with a seventh station as a development prototype and a spare. During the past year, the lab space was renovated to move an existing office space and house the new lab. Three-phase 208V power was installed, with the twist-lock outlets located around the periphery of the room and at a safe location. The laboratory is highly visible to ECE students and hoses the new Moog lab stations. The facility is located on the third floor of L. K. Downing Hall and may represent the finest teaching laboratory in the department.

4 Construction of New Laboratory Workstations

The purpose of the workstations is to enable students to explore the operation of ac and dc motor control when fed from adjustable speed drives. The workstations contain ac and dc motors, ac and dc drives, a dSpace DSP ACE1104CLP board, a motor drive board, measuring instruments, data acquisition and control, a variable transformer, a computer and laser printer, and a digital oscilloscope. Because of the kind equipment gift, the workstations utilize Moog and dSpace components almost exclusively. Third party vendors, such as Motorsoft, Schott Power System, ISE, and Tektronics were used where comparable components were not available from Moog. If the workstations were to be duplicated, equipment from a variety of vendors could be used with similar functionality. Howard University faculty, undergraduates and graduate students have designed and constructed these workstations, developed a solid understanding of how they operate and what can be done with them, and are presently debugging the systems and creating laboratory experiments. An electrical engineering Master's degree student has been instrumental in bringing this project together and is now working on the completion of the development of the laboratory experiments.

A block diagram of the proposed workstation is shown in Fig. 1. Each workstation consists of torque calibrated PM DC generator and one of the following 4 test motors: 1) brushless dc, 2) ac induction, 3) PM dc motor, and 4) switched reluctance. Each motor is fitted with resolver/encoder, and is coupled via a torque transducer. The entire workstation is interfaced to a computer-based Moog WinDrive graphical user interface system and dSpace-DSP controller board. The simulation runs completely on the real-time hardware DSP ACE 1104. The integrated I/O enables the students to connect the boards to the motor/load graphically. Real-Time Interface (RTI) generates the required real-time code together with Real-Time Workshop from The MathWorks. The drives' analog and digital I/O ports are connected to the PC, which acts as a master controller.

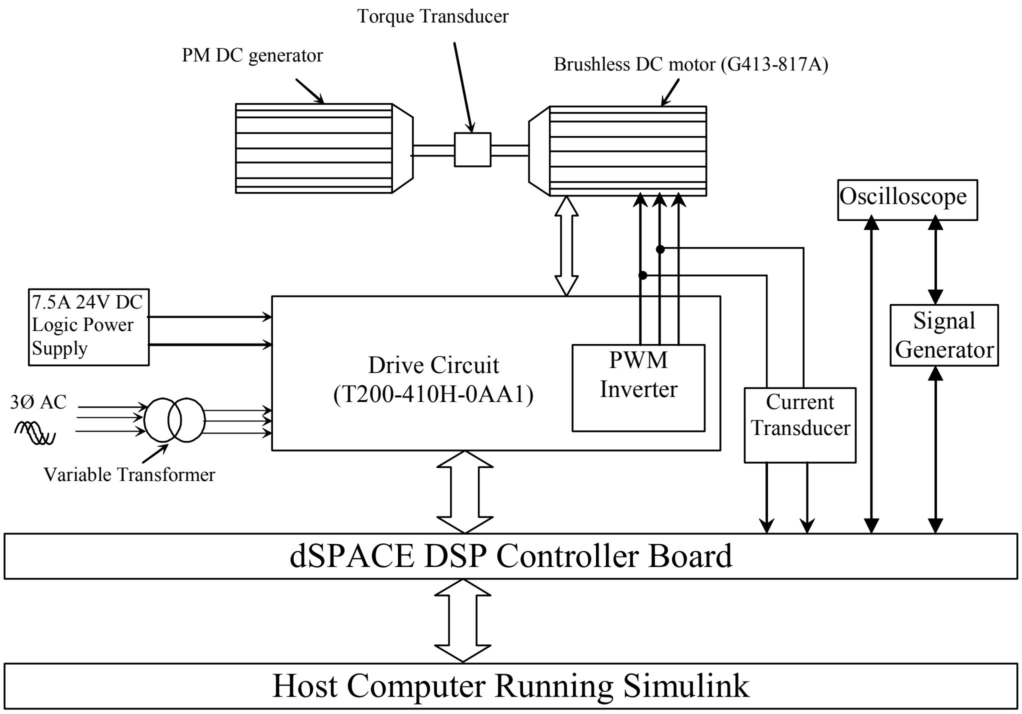

Fig. 1 Block Diagram of the Workstation

5 Hardware/Software Interface

In order to interface the motor/load units to the host computer, a data acquisition card for the PC is needed. Initially choosing the operating system for the host computer was a challenge. We wanted to find a board that would work with Real-Time Windows Target by MathWorks. Finding a compatible set of hardware and software drivers was also a challenge. One solution we considered is to use a general-purpose DSP board to perform data acquisition. The board would be outfitted with sufficient analog I/O, and could be programmed to decode encoder inputs using digital I/O. The other solution we considered was to use a generic I/O card with encoder inputs. This is a less-expensive approach, but places the control-loop processing burden on the main system CPU and so tends to decrease the control bandwidth that can be achieved. Our search led us to dSPACE DSP ACE 1104 CLP board that could meet our purposes from a hardware point of view. To concentrate fully on the actual control design task and allow students to gain experience with industrial control development tools, the Control Education board (dSpace DSP ACE 1104 CLP) is selected as the main interface between the motor/load unit and the host computer. One of the salient features of the DSP ACE 1104 CLP Kit is the ease of building real-time applications.

In order for students to access the I/O dSpace DSP ACE 1104 board to control the motor drive, a software interface to the board is required. Rather than requiring that the students write C-language code and interrupt-service routines we chose to use a MATLAB/SIMULINK/ RTW/RTLT interface. Students can choose from a broad range of control design toolboxes. SIMULINK conveniently expands MATLAB with a block-oriented, graphical interface. The Control-Systems Toolbox, in particular, greatly aids control-system analysis and design. SIMULINK is a block-diagram graphical-user-interface based simulation package that works within the MATLAB environment and allows linear and nonlinear, continuous-time and discrete-time simulation. The student writes no code at all. The dSpace DSP ACE Kit has software tools, which help the students to control experiments. For example, the students can display or store variables and change parameters with ControlDesk panel.

6 Feature of the Workstations

Fig. 2 shows an overall view of the workstations, with the drives, motors, PM DC generators as loads, torque transducers, variable transformers, and power supplies mounted on the top shelf, dSpace DSP board, oscilloscopes, function generators, and PCs mounted at the bottom. Much of the wiring has been linked so that students can see how the components are interconnected. Safety sockets have been used so that students can connect to these wires with modern “banana” plugs to measure speed, position, and current without the risk of contacting exposed conductors. Voltage isolators are used to connect the input-output probes to the dSpacs DSP board. This eliminates the chance of ground loops and other short circuits as well as over-voltage to the input ports. Fig. 3 shows a snapshot of two graduate students testing the control workstations.

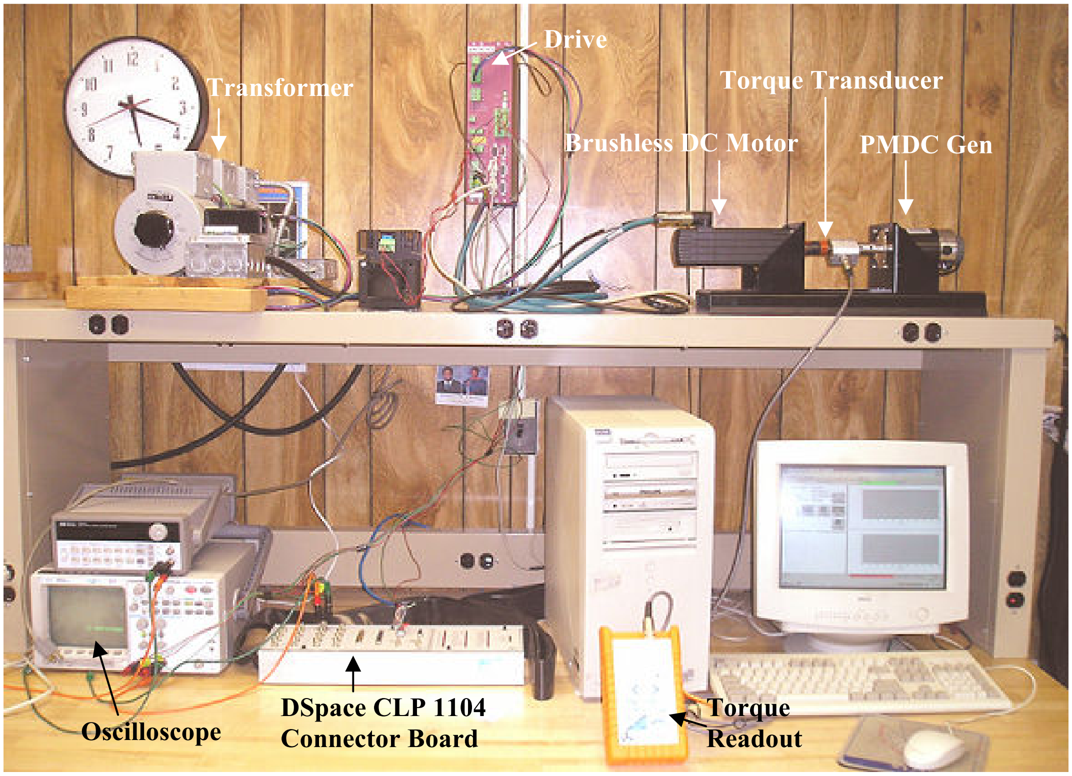

Fig. 2 Motor Control Workstation

Fig. 3 Graduate Students Testing the Laboratory Workstations

7 Development of Laboratory Experiments

Last summer we initiated the process of generating laboratory experiments for students to use with the workstations. During the 2005 spring semester, the workstations will be integrated into the laboratory courses: EECE414: Control Systems Laboratory, EECE408: Linear Control Systems, and EECE418: Motor Dynamics and drives. Furthermore, it will be used for course projects in EECE499: Embedded Industrial Control, EECE318: Energy Conversion I, EECE324: Energy Conversion Laboratory and EECE691: Embedded Computing and for Senior Design Projects and Independent Study Topics. These courses are designed to coordinate with each other as much as possible so that the experimentation complements and illuminates the theory. The plan is to use the workstations for six-ten experiments (outside of normal class-time). All experiments utilize a common setup composed of computer with dSpace DSP software, motor drive board, and motors. These experiments include but not limited to: dc motor drive operation and control, ac motor drive operation and control, and industrial control systems. Each experiment provides insight into the hardware aspects of the controller.

Additionally, a user manual for the laboratory experiments and handouts of each experiment are developed for the students. The student manual includes, for each of the experiments, the experiment objectives, the actual experimental procedure, and a section listing a series of discussion questions, which aid and guide the student in understanding the experimental results. The questions are intended to direct the post experiment analysis of the results, focusing on the objectives of the laboratory experiment. Specifically, the manual explains basic operator interface functions such a selecting control algorithm, entering set-points, monitoring actual position, entry of tuning parameters, and initiation and termination of control action. Also, a brief explanation of the operation of the dSpace DSP board is presented since it will be used throughout the experimental procedure. In addition, the user manual details the actual structure of the hardware and provides a view of the overall system from the student's perspective. The snapshots (Figs. 4 through 7) that follow demonstrate some of the items could be explored using Moog WinDrive graphical user interface system. Additionally, students can utilize digital oscilloscopes to demonstrate their experimental results. Figs. 8 through 11 show snapshots of the tracking performance of the PI and bang-bang controllers for a position control.

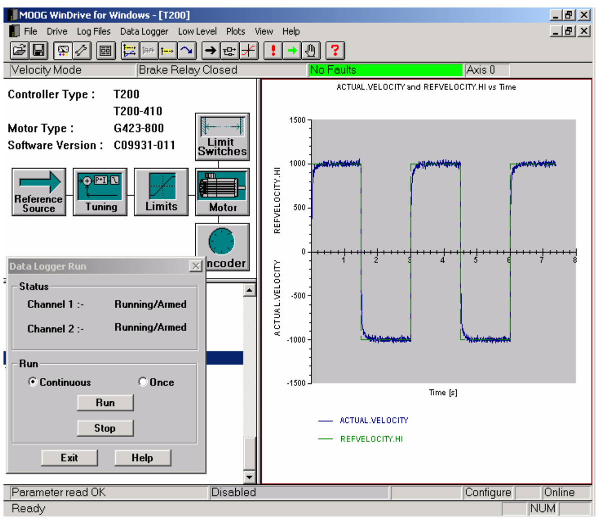

Fig. 4 Speed tracking of a square-wave trajectory

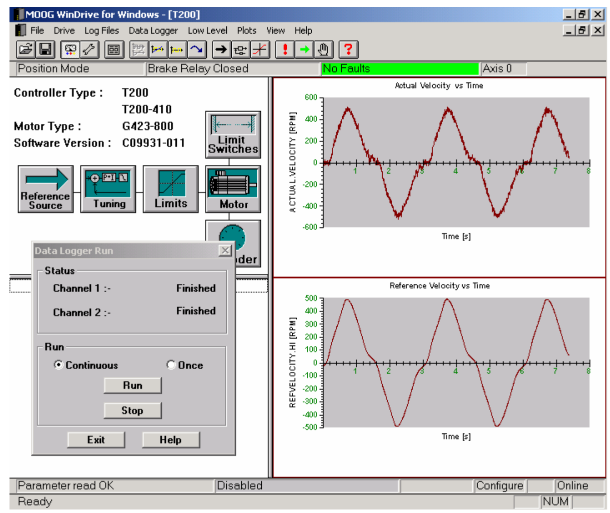

Fig. 5a) Speed control, 5b) Reference speed

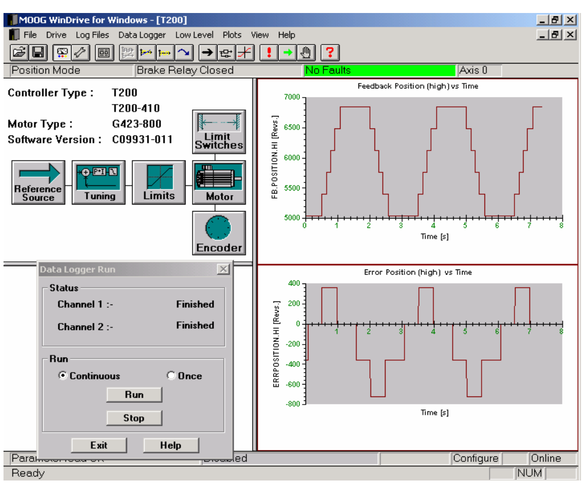

Fig. 6a) Position control, 6b) Feedback error

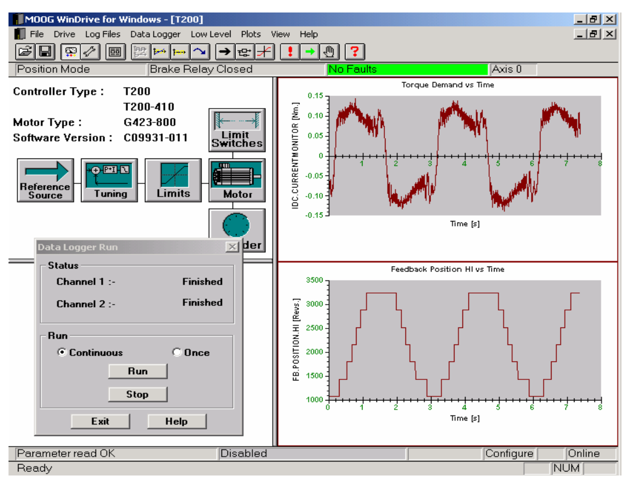

Fig. 7a) Current control, 7b) Position control

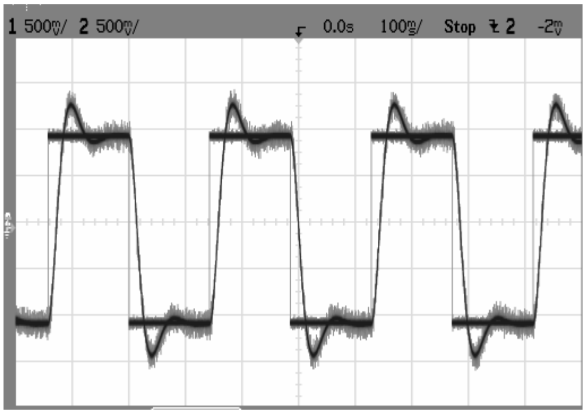

Fig. 8 Square wave position tracking for a PI controller, K_p =1, K_I=0.1

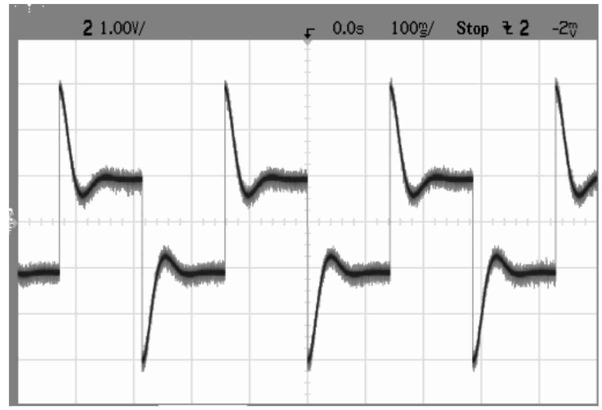

Fig. 9 Corresponding control signal for the PI controller

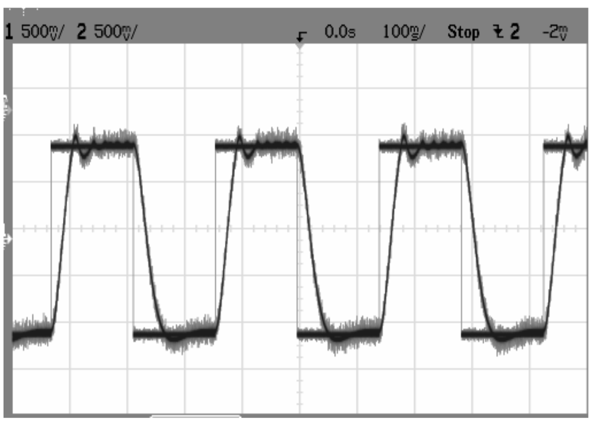

Fig. 10 Square wave position tracking for a bang-bang controller, D = 0.85, C=1

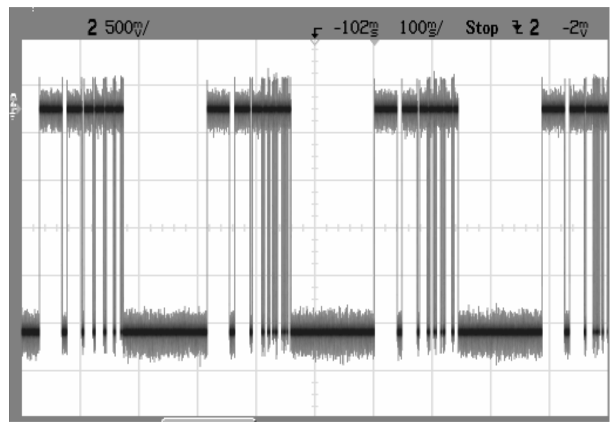

Fig. 11 Corresponding control signal for the bang-bang controller

8 Conclusions

The new motor and control laboratory provides an excellent opportunity for our students to learn about modern motor control and power electronics applications in a safe and flexible environment. The workstations offer many possibilities for experimentation on motors and drives similar to those that students will counter in the real world. We are just beginning to incorporate these workstations into our classes. At this stage, the lab had not been implemented and used by students. Students' responses and measurements of their success will be reported in the future.

9 Acknowledgements

Special thanks to Tom Greetham, Pete Sergi, Tina Stenhous, Jim Silliman and others at Moog Aerospace for their generous gift. And without their support, this project would not have been possible. Thanks to Dean Johnson and Dr. Chouikha for providing departmental support for the

laboratory space and expenses involved in peripheral equipment, construction of the workstations and development activities.

10 References

1. L. Gil, E. Blanco, and J. Auli, "Virtual Laboratory Concept Applied to Strain Measurements," European Journal of Engineering Education, Vol. 25, No. 3, pp. 243-251, April 2000.
2. A. Jimoyiannis, and V. Komis, "Computer Simulations in Physics and Learning: A Case Study on Students' Understanding of Trajectory Motion," Computers and Education, Vol. 36, pp. 183-204, 2001.
3. [3] V. Gomes, et al., "Web-Based Courseware in Teaching Laboratory-Based Courses, " Global Journal of Engineering Education, Vol. 4, No. 1, pp. 65-70, 2000.
4. D. S. Bernstein. Control experiments and what I learned from them: A personal journey. *IEEE Control Systems Magazin*e, 18(2):81–88, April 1998.
5. D. G. Alexander and R. E. Smelser, " Delivering and Engineering Laboratory Course using the Internet, the Post Office, and a Campus Visit," Journal of Engineering Education, Vol. 29, No. 1, pp. 79-84, January 2003.
6. Y.-C. Chen and Jason M. Naughton, "An Undergraduate Laboratory Platform for Control System Design, Simulation, and Implementation," *IEEE Control Systems Magazin*e, Vol. 20, No. 3, pp. 12–20, June 2000
7. R. M. Goff, and M. H. Gregg, "Hands-on Engineering Laboratory at Virginia Tech," the Innovator, The SUCCEED Newsletter, Vol. 11, pp. 12-15, 1999.
8. G. Plett and D. Schmidt, "Multidisciplinary lab-based controls curriculum," *CD-ROM Proceedings, 2001 ASEE Annual Conference & Expositio*n, Albuquerque, NM: June 2001.
9. Carnegie-Mellon University, <http://www.distance.cmu.edu>
10. Drexel University, <http://www.drexel.com>
11. The University of Tennessee at Chattanooga, <http://cbem.engr.utc.edu/>
12. University of Minnesota, <http://www.ece.umn.edu/groups/PowerElectronics_Drives/>
13. M. Ogot, G. Elliott, and N. Glumac, "An Assessment on In-Person and Remotely Operated Laboratories," ASEE Journal of Engineering Education, Vol.29, no. 1, pp. 57-63, January 2003.
14. L. Schmitt. U of I's control systems lab one of premier labs in country. University of Illinois at Urbana-Champaign "Ingenuity", 4 (1), 4, March 1999.

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