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Integrating Computer, Control and Communication (C^3) in Mechatronic Design Process

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ABSTRACT

Mechatronic system design has received considerable attention over the past decade. This trend has been further accelerated by the rapid advancement of computer, communication, and control (C^3) technologies and the need for technology integration in modern manufacturing, which depends on the harmonious blending of many different technologies. In helping to prepare our future mechanical engineers to take maximum advantages of the C^3 in designing cost-effective products and processes, a sequence of laboratory and lecture courses related were revised. In this paper, we discuss the sequence of courses and laboratories that provide the essential experiences need for integrating the C^3 in the mechatronic design process in the Woodruff School of Mechanical Engineering at Georgia Tech.

1. INTRODUCTION

In the past two decades, rapid advancement in microprocessor technology has enabled that the control, in systems of any complexity at all, can be implemented with several computers operating cooperatively. The integration of computer, communication, and control becomes essential in many processes and products. Clearly, students must have hands-on experience with the physical implementation of mechatronics. Mechatronics is appropriate for students from several traditional disciplines. Finally, graduates also work in the field of mechatrnoics should expect to work in interdisciplinary teams. The confluence of digital technologies has also made it possible to provide a fertile environment to support the instruction of students in many domains. In this paper, the curriculum structure for preparing students in learning mechatronic system design at Georgia Tech is discussed.

However, many educational institutions find it difficult to fit mechatronics, “the synergistic combination of precision mechanical engineering, electronic control, and systems thinking in the design of products and manufacturing processes [1],” within the traditional course structures of electrical, mechanical, industrial, computer and other engineering departments. Courses addressing instrumentation, design, modeling, and control of mechanical and electrical systems may be found in individual academic units. However, few specific courses and laboratories have been designed to offer students an opportunity to integrate their learning experiences across their disciplinary boundaries. In this paper, the role of integrating computer, communication and control in designing mechatronic systems and in developing educational technology to bridge the gap between theory, laboratory learning, and design process are discussed.

The remainder of this paper is organized as follows: Section 2 outlines our course structure preparing our students for mechatronic system design. Sections 3 and 4 discuss the approach for teaching the C^3 which leads to the project design examples in Section 5. Finally, we summarize our observations and conclusions in Section 6.

2. COURSE SEQUENCE ON MECHATRONICS

Our course structure preparing our students for mechatronic system design has been structured in Figure 1. The sequence consists of two parallel tracks; namely, system modeling and control theory and laboratory practice. System dynamics and controls have played a vital role in the advancement of engineering, science, modern manufacturing, and mechatronics. They provide a comprehensive treatment of the modeling, analysis and design of continuous-time and digital control systems. In the Woodruff School of Mechanical Engineering at Georgia Tech, these two courses are ME3115 System Dynamics and ME4445 Automatic Control. The prerequisites for system dynamics are courses in introductory differential equations, circuit analysis, basic computer fundamentals, and mechanics. The prerequisite to automatic control is a course in system dynamics.

In parallel with the theory courses, the lab sequence is ME3056 Experiment Methodology; ME4052 Mechanical Systems Laboratory; and ME4055 Expoerimental Engineering. The ME 3056 is the junior-level instrumentation and transducer course. Students may choose from one of the following two tracks in the second course: ME4052 Mechanical Systems Laboratory or ME4054 Thermal Systems Laboratory. In ME4055, students work in a team of four in a quarter-long project that involves a capstone, open-ended experience for the students.

In addition, we offer a two-course sequence in digital control systems covering advanced theory, design and implementation of discrete-time systems. ME6437 focuses on the theory and simulation technique and ME6438 reinforced synthesis methods with hands-on real-time laboratory experience.

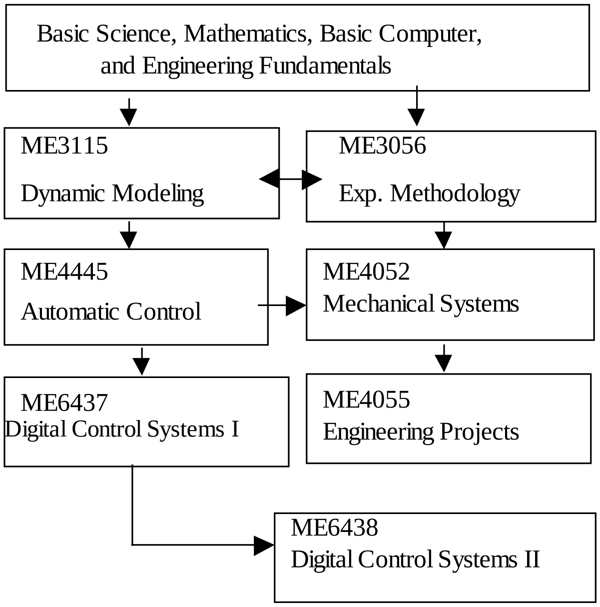


Figure 1. Mechatronic Course Structure

3. Microprocessor-based Eng. Methodology Laboratory

The fundamentals and applications of microprocessors for real-time computing, data acquisition and control begin in ME3056, which has been designed to familiarize the students with the basic instrumentation in mechanical engineering. Learning takes place through a combination of classroom lectures, reading, laboratory exercises, team discussion, and interaction with TA’s and instructor. With nine different labs, it covers several major fields of mechanical engineering in a quarter (10 weeks). Due the large number of students going through the lab, students are grouped in pairs in seven of the nine experiments listed in Table 1.

Table 1 ME3056 Experiments

Exp.	**Laboratory**
1	Instrument performance specification
2.	HC11 µP-based data acquisition
3A	HC11 µP-based DC motor open-loop speed control
3B	HC11 µP-based DC motor closed-loop speed control
4	Heat transfer experiment
5	Stress, strain, force, and displacement measurement
6	Viscosity measurement
7	Acoustics and vibration measurement
8	Optics, lasers, and interferometry

The facility provides each student a Pentium/PC networked to a microprocessor experimental setup as shown in Figure 2 and to the instructor host Pentium/NT. The fully networked facility enables the faculty and the TA's an effective means to evaluate the students' pre-lab preparation and post-lab partner evaluation through computer-assisted-assessment software.

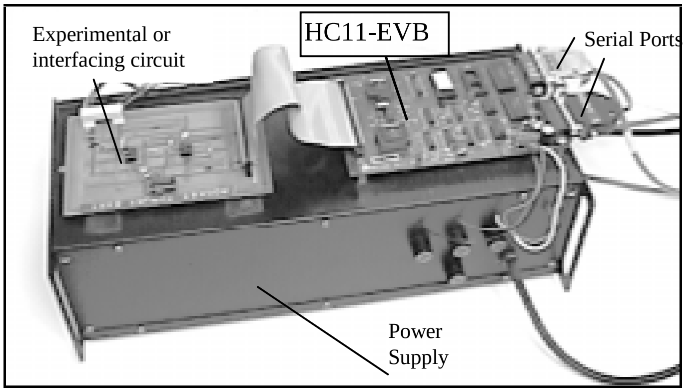


Figure 2 Microprocessor-based experimental setup

As shown in Table 1, the essentials of microprocessor for mechanical engineers are introduced at the very beginning of the laboratory courses and reinforced with a number of experiments in a wide range of different topics. The first µP experiment includes the following elements:

1. µP hardware architecture and programming structure:
2. Data transfer between the µP's through serial and parallel port communications.
3. Digital I/O interface and control.
4. Data acquisition with A/D and D/A conversions
5. Real-time computing BASIC11, machine and assembly languages.
6. Real-time clock and control using interrupt service routines (ISR).

Built upon these fundamentals, the students are given the opportunity to apply the µP to perform a variety of tasks. A typical example is to develop a computer algorithm for speed control of a DC motor as shown in Figure 3.

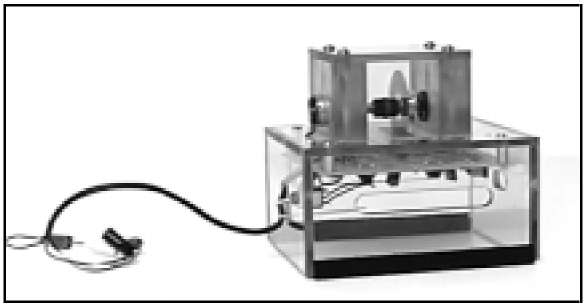


Figure 3 Experimental setup for µP-based motor speed control

As shown in figure 3, the system consists of a pair of dc motors (one of which serves as a tachometer), an optical encoder and a bipolar half bridge motor driver. With the setup, the students are able to gain practical experiences of analog and digital devices, and open loop and closed-loop machine control based on the principle of pulse-width-modulation and successive approximation respectively.

4. CONTROL SYSTEM DESIGN TECHNIQUES

The control system design techniques are covered in a traditional control course ME4445 and a two-week experiment in ME4052. Unlike the ME3056 lab where the μP-based control experiments focus on the essentials and components that made up typical mechatronic system, students in ME4052 are required to model and analyze the system and to apply the model in mechatronic system design to meet the control system specifications.

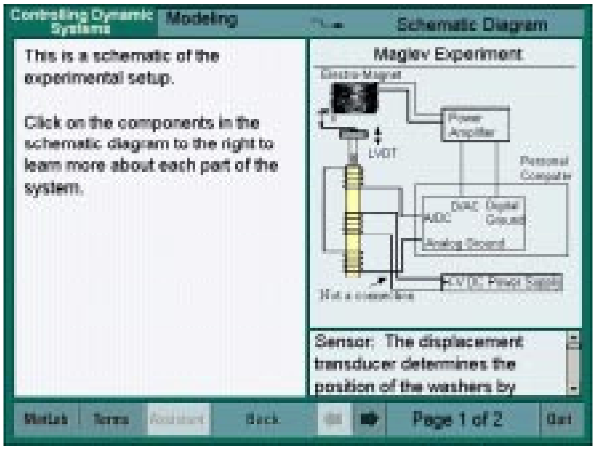
A survey conducted during the 1992-1993 academic year in the Woodruff School of Mechanical Engineering at Georgia Tech indicated a relatively high attrition rate (D, F, and W) of senior-level students participating in the ME4445 Automatic Controls course. Since then, faculty in the ME department’s Automation and Mechatronics Research group discussed ways to improve the students’ performance. The faculty group sensed that although students conducted experiments related to system dynamics and controls in the existing curriculum, the students could learn substantially more from the lab courses. *How closely should laboratory courses be tied to ”theory” courses?* When the purpose of the lab is to teach experimentation, one viewpoint was that a “vertical laboratory program” should be implemented in a way that is nearly independent of the theory courses. This kind of laboratory operation has proved to be efficient and cost-effective. This efficiency, however, has largely been achieved at the expense of the link between laboratory and theory, which is essential in learning dynamic systems and control. For this reason, a control system design (CSD) software was developed [2] [3] to take maximum advantage of the laboratory experience and of full-motion video to improve students’ comprehension of dynamic systems and control. The CSD aims at achieving the following objectives:

(1) to improve dynamic visualization by incorporating illustrative application examples and laboratory practices in lectures,
(2) to provide a self-directed learning environment, and
(3) to expose the essence and significance of mathematical expressions more effectively in laboratory examples.

Although there are as many different semantic representations of the CSD knowledge domain as there are experts in the field, the following representation of the design method is the most expandable and transferable for students at Georgia Tech.

- Problem statement and design specifications
- System modeling and linearization
- Controller design with stability, steady-state and transient analysis)
- Simulation and implementation of the closed-loop system

Figure 4 illustrates an (actual) laboratory setup on magnetic levitation that challenges the students and requires them to apply the control system design theory that they learned to solve the problem. This setup utilizes components that our students have learned in their co-requisite ME3056, which includes an LVDT, a power amplifier, and a personal computer with A/D and D/A converters. The schematic includes hypertext that allows the students to review the fundamental of the instrumentation involved. Figure 5 shows a screen shot of the guided design example, which provides the students a means to compare their analysis with pre-recorded video clips of experiments for several selected PID gains.

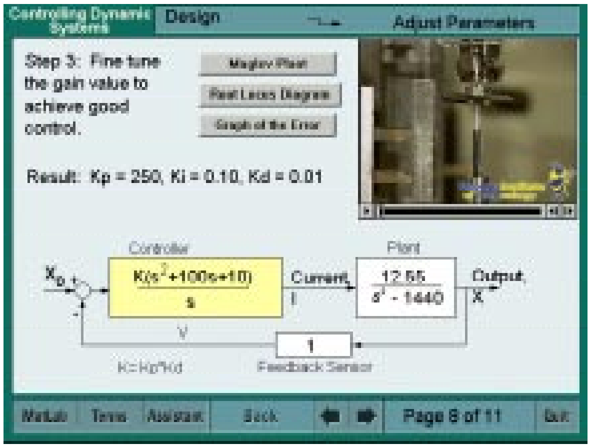


This is a schematic of the experimental setup.

Click on the components in the schematic diagram to the right to learn more about each part of the system.

Sensor: The displacement transducer determines the position of the washers by

Figure 4. Screen shot illustrating the experimental setup



Step 3: Fine tune the gain value to achieve good control.

Result: Kp = 250, Ki = 0.10, Kd = 0.01

Figure 5 Screen shot of a typical guided example

5. SELECTED STUDENT PROJECTS

The most important and productive approach to learning is for each student to rediscover and receate anew the answers and methods of the past. The idea of the ME4055 Engineering project is to present an open-ended problem and point to some of the methods for solving the problem. By confronting the students with a problem but with not a finished solution, this experimental engineering approach encourages the adventure of students to a dusty heap of theorems. The students are required to complete a term project that has been proven to be a major creative enterprise. The following illustrates two selected student examples.

Example 1

In ME4055, students use the extensive facilities in the lab to undertake the design and integration of a μP-based mechatronic system. The engineering project is quarter-long, beginning with team forming, developing a three-page proposal, designing and constructing hardware, and the development of all necessary control algorithms, and concluding with extensive documentation. In addition, each student is given an opportunity to present orally a part of the project. Students use considerable amount of knowledge acquired in the previous courses including analysis, synthesis and experimental techniques in the implementation of the project.

Figures 6 and 7 show the schematics of an example project, where the students designed and developed an active joystick with force feedback capabilities for remote Tele-operation so that the operator can remotely maneuver the manipulator with dexterity and sensitively. A specific example of where a force feedback joystick can be used is in the nuclear industry.

The students were provided with a one-DOF robot finger on which a strain gage is mounted and a PC with a DASH-16 Analog I/O broad. Thus, the students' design includes the following elements:

(1) As shown in Figure 9, a DC motor was incorporated in an off-the-shelf joystick, which has been designed such that the motor would exert a counter torque to the joystick motion.

(2) Electrical circuits are designed and built so that the system's instrumentation can be "read" by the computer.

(3) A PID controller was designed and a program was written to control the system. Basically, the program receives signals from the joystick potentiometer and the strain gage on the robot finger. Based on these signals, the control algorithm computes and sends control signals to the joystick motor and the motor/ball-screw system driving the finger. When the finger comes in contact with an object, the μP would send a control signal to the joystick motor based on strain gage signal to resist the motion in the direction that the joystick is being manipulated.

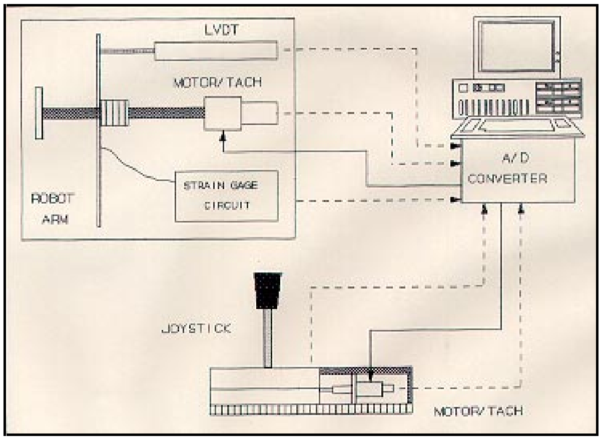


Figure 6 Schematics of the experimental setup for an active joystick

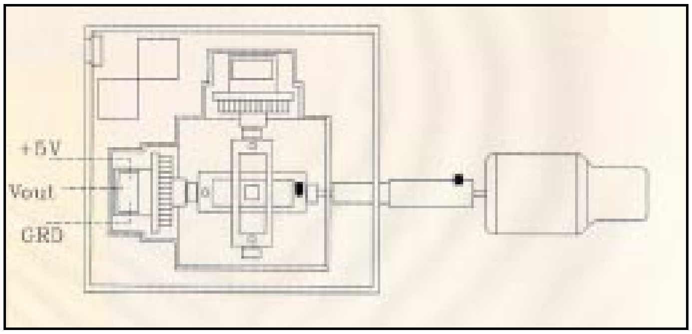


Figure 7 Schematics of the prototype active joystick

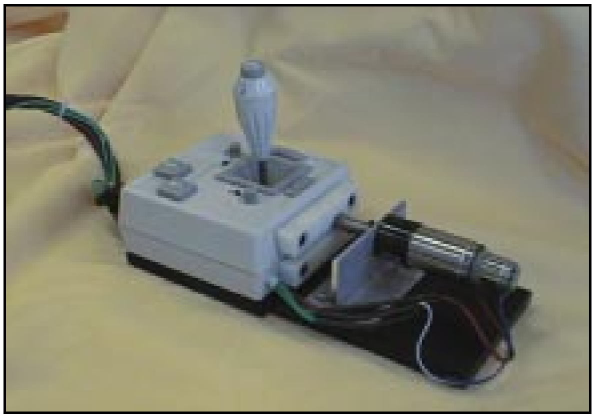


Figure 8 Prototype active joystick

Example 2

Figure 8 illustrates another creative mechatronic system design project where a digital vision system as a feedback element to control a vehicle to follow a prescribed path. To illustrate the important of C^3, each student group was provided with a non-conventional flexible integrated vision system (FIVS) which has been developed at Georgia Tech to overcome some problems associated with the use of conventional vision systems for real-time control [4].

The project requires the students to choose a solution to achieve a large range of motion by integrating the vision system on the vehicle. The on-the-vehicle configuration requires a set of landmarks or fiducial patterns as a medium, when analyzed by the vision system, to locate the vehicle. The basic concept is illustrated in Fig. 8. During operation, the vision system takes pictures of the fiducials periodically while the vehicle is moving, captures the patterns within its field of view, stores and analyzes the images, then returns the vehicle's locations.

The tasks accomplished by the students are as follows: The cart was constructed from the chassis and motors of a radio-controlled car. This reduced the time required to build the cart, allowing more time for controller design. The body and radio control electronics were removed and a vision camera was mounted to the remaining chassis. For a quick and smooth maneuverability, a three-wheel configuration with two rear driving wheels and a ball-joint-like universal front wheel was chosen for the autonomous vehicle. The system integrates a three-wheeled autonomous vehicle, an on-board FIVS, a ceiling fiducial board, a digital signal processor (DSP) DS1102 board with A/D and D/A converters, and an Intel 486 as central computer. The prototype setup is shown in Figure 10. An image showing the fiducials is displayed in Figure 11.

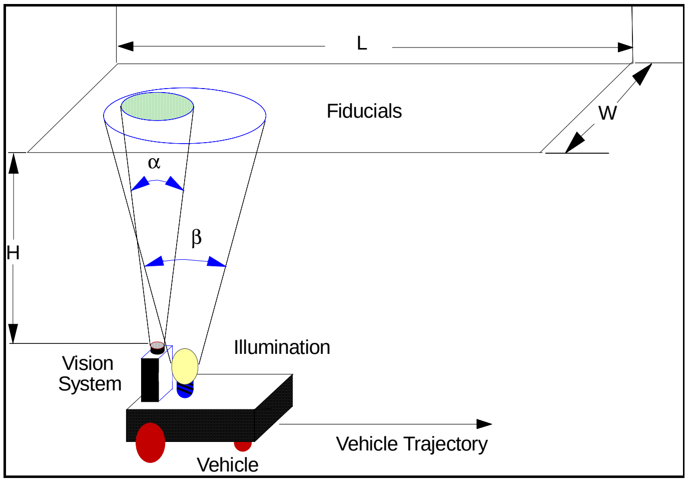


Figure 9

As control functions were implemented using DSP and/or computers, the controller has been designed in the discrete-time domain. First, the motor dynamics is discretized state-space. The pole placement technique was then used to design the regulator in order to obtain specified time response of the system. The vision system was used to measure only the vehicle's position with a reduced-order observer designed to estimate the vehicle's velocity necessary for full state feedback. Finally, a digital tracking filter was designed to generate the reference input for following a desired trajectory. Course organization, derivation and results of the implementation can be found in [5] [6].

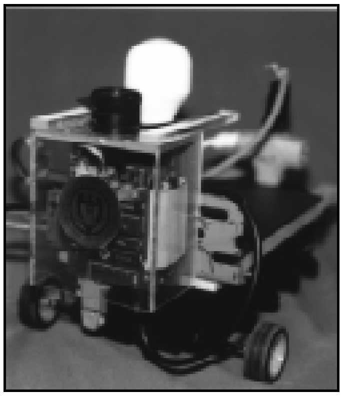


Figure 10 FIVS guided car

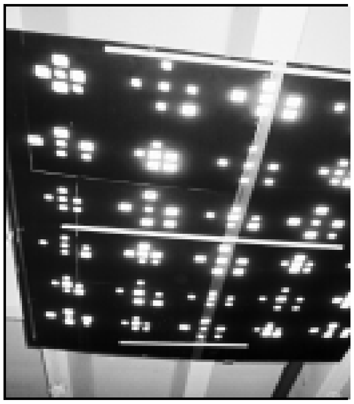


Figure 11 Fiducials on ceilings

6. CONCLUDING REMARKS

In summary, the curriculum structure, courses and selected student project examples of mechatronic system design in the Woodruff School of Mechanical Engineering at Georgia Tech were presented. The role of computer, communication and control in teaching mechatronic system design was discussed and emphasized. The structure consists of two independent tracks, a theory and a laboratory sequence. To bridge the gap between theory and laboratory learning, we have developed a CSD software to aid visualization between the domains.

REFERENCES

[1] Comerfeld, R., "Mecha ... what?" IEEE Spectrum, vol. 31, no. 8, 1994, pp. 46 -49.

[2] Lee, K.-M., Daley, W., and Hurley, R. P. III, "Technology in Support of Instruction in Higher Education," Proceedings of the World Conference on Engineering Education, Minneapolis-St.Pual, Minnesota, 15-20 October, 1995.

[3] Lee, K.-M., Wayne Daley and Tom McKlin, "An Interactive Learning Tool For Dynamic Systems And Control," 1998 International Mechanical Engineering Congress And Exposi[4] tion (IMECE) - Dynamic Systems and Control Division, Anaheim, California, November 19, 1998.

[4] Lee, K. M. and Blenis, R. Jr., 1994 ``Design Concept and Prototype Development of a Flexible Integrated Vision System," Journal of Robotic Systems, Vol. 11, No. 5, 1994, pp. 387 - 398.

[5] Lee, K.-M., Zhou, Zhi, Blenis, Robert, and Blasch, Erik, "Real-Time Vision-Based Tracking Control Of An Unmanned Vehicle," Mechatronics, Vol. 5, No.8, October 1995, pp. 973-991.

[6] Lee, K.-M., "Vision-Based Digital Controlled Systems Using Real-Time Multiprocessing," 1995 International Mechanical Engineering Congress And Exposition (IMECE), Invitded Session On Eduction - Automatic Control Laboratory Experiments In Graduate Engineering Education. San Francisco, California, November 1995.