Challenges and Directions for Integrating Mechatronics into Early Design*

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This paper presents the initial results of integrating mechatronics into a large second-year design course. Issues related to course objectives, implementation, costs and initial results for the course are presented as well. The initial results generated from a group of 20 students provides some insight into the ultimate goal of implementing the enhanced curriculum for approximately 300 students per year.

INTRODUCTION

'MECHATRONICS' is a buzz word that can be seen in a wide variety of curricula throughout the world. It is the combination of mechanical and electronic system design and implementation. The reality is that most engineers work in the world of mechatronics as there are relatively few systems that are purely mechanical or electronic. The difficulty facing our students is that electromechanical system design and implementation is not taught until advanced courses in the undergraduate curriculum. All too often, these courses are elective courses and are not taken by all of the students. To address this curricular shortcoming, the design course taken by second-year students in the School of Mechanical Engineering at Georgia Tech is being enhanced to incorporate a hands-on mechatronics experience.

To fully prepare students for industrial environments, they must be capable of addressing a variety of basic issues in electromechanical system design and implementation. Furthermore, they must understand how to effectively communicate and utilize all of the modern tools that are at their disposal. The course provides a platform to accomplish this task. Initially targeted at mechanical engineering students, it provides them with the necessary electronics control background to address a variety of situations in the real world.

The electromechanical systems used by the students were developed and fabricated within the School of Mechanical Engineering. They are modular in nature permitting a relatively simple plug-and-play type of approach. One may think of these modules as an electromechanical set of Lego, similar in nature to the new Lego MindStorm system, but much more powerful and flexible.

The controller or 'system brains' employed, is a BASIC Stamp 2 (BS2) (see Fig. 1). It is based on a PIC (peripheral interface controller) chip that is typically found on appliances such as microwave ovens and washing machines. The BS2 is capable of executing approximately 4000 instructions per second and is designed to be a simple tool for controlling electrical systems. The Electrical Interface System (EIS) was designed in the School of Mechanical Engineering at Georgia Tech as the foundation by which the students can make use of the BS2. The Mark I EIS, shown in Fig. 2, is the first generation prototype of the unit. It consists of two separate boards. The upper board is the BASIC Stamp's 'Board of Education' and is sold with the BS2 at a cost of approximately $80. The lower board contains the electrical connections for several driver circuits including the motor controller, the motor encoder feedback and the various actuators. The lower board is produced on a standard PC board prototyping system and is readily replicated via a variety of PC board manufacturing techniques. The next generation EIS, Mark II, is currently under development and scheduled for deployment in the Fall semester 1999. The Mark II EIS consists of a single board with the BS2 unit directly integrated into the board. A description of the lessons learned with respect to hardware is presented later in this paper.

Since the students design and build these electromechanical devices, they are afforded the opportunity to actually receive some hands-on experience in machining and electronic assembly. As this is the first design course taken by the students, it provides them with some motivation for their other courses during the remainder of their years at Georgia Tech. It also provides a strong platform for their more advanced design and laboratory courses yielding better prepared engineers.
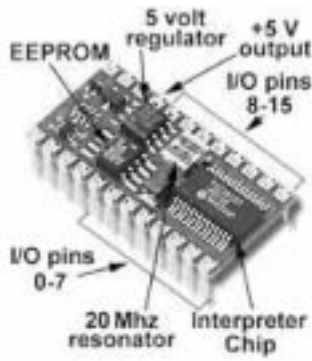

Fig. 1. The basic stamp.

Fig. 3. The competition track.

THE COMPETITION/PROJECT

The project is a well specified and fixed competition that is assigned to teams consisting of four students. The competition requires the students to design electromechanical systems that perform a specific task. The course is designed to be fun and to permit a wide spectrum of learning experiences. However, a student team's project grade is dependent on how well their system performs in the competition. The course is designed such that even a student whose system performs poorly in the competition does not irreversibly harm their grade. During the project the students are given a set of raw materials that they use to fabricate a system. Nominally, they use the small machine tools (mills and lathes, as well as band saws and drill presses) in the design studio for this task. The project used for the Spring quarter 1999 was designed for a purely mechanical system; however, one special studio section of 20 students (5 teams of 4 students) employed electrical systems. The project is described in the remainder of this section.

The goal of the studio project is for a team of four students to design a device that places a CD ROM on a target. Both the mechatronic section as well as the purely mechanical sections are provided with the same project. The CD ROM is placed 3 feet in front of a team's device and 2 feet from the edge of the track to the device's right as shown in
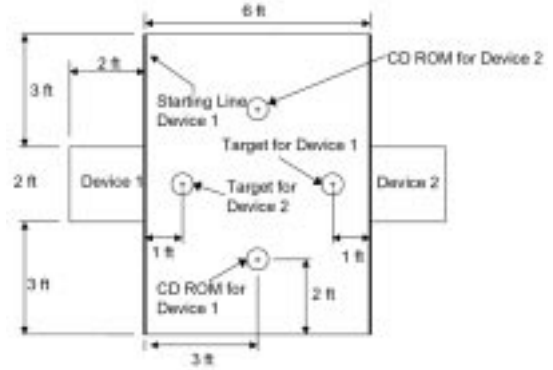
Fig. 3. The target is located 1 foot in front of the opponent's device (4 feet directly in front of the team's device). The objective is to place the CD using only energy from 5 mouse traps and gravity. The mechatronic section has use of several electrical actuators as well. These actuators are described in the following section.

To make the competition more interesting, an opposing team will attempt to move the CD placed 1 ft in front of their device and 1 ft from the edge of the track to their right to a target location. Points are awarded based on the accuracy of the system; thus, the accuracy of the device is paramount, as is its reliability and repeatability. Each device will compete against the other devices in a double elimination competition. The winner of each competition is the system whose CD is closest to the target position. The device must conform to the rules provided. Part of the device's performance grade is based on its ability to place the CD ROM on target. Concentric circles are drawn around the target as shown in Fig. 4. The point values of placing the CD within each circle are also shown in the figure.

ACTUATORS AND SENSORS

Presently, the actuators employed by the students include two DC motors with encoder feedback, two solenoids and two shape memory alloy (SMA) actuators. The entire system is
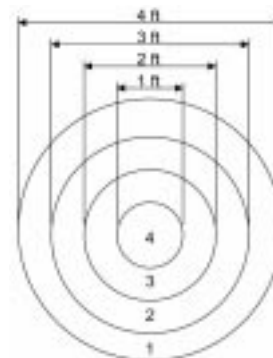

Fig. 2. The Mark I EIS.

Fig. 4. The target area.

powered by a small 12 V lead acid battery. The students are provided with a trickle charging unit that both powers the system using 120 V AC as well as charges the battery. The energy capacity of the battery is such that it can easily supply the power requirements of the system, including all actuators, for more than a day. Thus, the students are instructed to charge their batteries over night, every night. The lead acid battery does not have any memory; thus, daily charging does not reduce the life span of the battery. The only sensors that are currently used for the current system are a set of microswitches.

COSTS

All of the components used for the systems are off-the-shelf items to keep the cost minimal. Prototypes of these systems were fabricated and used by a single section of the course to test the concepts of microcontroller utilization in a design class. As an example of costs, the microcontroller with a manual is approximately $60, A/D chips (not used in this particular competition) used for sensor interfacing cost are approximately $1.50, and standard motors that can be used by this systems cost approximately $20. The reality is that the systems are relatively inexpensive ($350 per group); however, it must be remembered that there is a large number of groups in the course (approximately 40 groups per semester).

While the cost of the individual systems is quite reasonable, other baseline expenses must be considered. There are a set of major start-up costs involved in developing and fabricating the mechatronic systems. The bulk of these costs are due to the small machine tools used by the students ($500 per machine tool) and the printed board prototyping system for the electronics fabrication.

Other significant start-up costs include the benches required to house the lathes and mills (see Figs 5 and 6), and basic tooling (mills, boring bars, drills, taps, etc.). The other major cost component is personnel time, including the teaching and support personnel. For the large class size at Georgia Tech, the equivalent of one full-time technician and 6 TA's are employed by the course. This is a substantial commitment in funds.
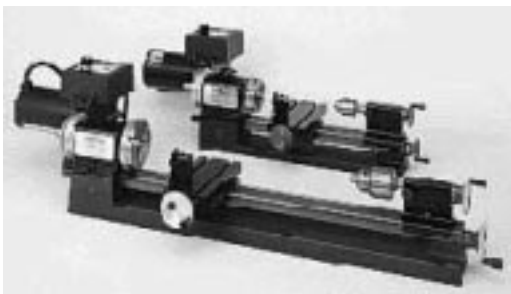

Fig. 5. Standard lathe.

Fig. 6. Standard mill.

LESSONS LEARNED

A number of lessons were learned during the first use of these systems in a studio section of 20 students. The first and most important lesson learned is that the average student has little if any experience with both basic hardware and low level programming. This fact surprised the staff of the design course. The largest problem, by far, was the lack of hardware experience. In particular, a number of EIS units were shorted when the students attempted to do some basic wiring while the unit was powered. This resulted in a number of incidents that damaged the board or its components. The students quite often did not wire the actuators and sensors correctly, even though they were provided with the appropriate wiring diagrams and several lectures on wiring. Nominally, this did not damage the EIS; however, there were instances where the motor drivers were damaged due to incorrect wiring. To address this issue, the connections to the EIS are being standardized such that actuators and sensors can only be attached as specified. Such attachments reduce the flexibility of the system; however, they provide a substantial reduction is damage to the EIS and actuators. Furthermore, the Mark II EIS units are being designed with either fuses or circuit breakers. There is still a significant debate as to whether circuit breakers or fuses should be used. Fuses can be by-passed (e.g., aluminum foil in the fuse holder) and circuit breakers permit the easy ignorance of overload problems.

From a software perspective, it was observed that while students have experience with higher level programming languages such as BASIC, C and C++, few of them have experience with lower level concepts such as byte programming or bit control of ports. For example, the concept of setting the 16 I/O ports of the BS2 unit by setting a two byte variable bit by bit (16 bits) to identify whether a port is an input (0) or an output (1), was foreign to most students. Terminology such as least significant bit (LSB) and most significant bit (MSB) was generally foreign to the students. To remedy this, several new lectures and studio exercises were developed and implemented.

Fig. 7. The winning design.

Fig. 8. The second place design.

One major concern of the course staff was the possibility of an increased work load on the students. This concern did not prove valid when the work load of the special mechatronics section of the course was compared to that of the standard sections.

CURRENT STATUS

Currently, one section of 20 students has been run at Georgia Tech. The students were provided with a limited set of actuators and sensors, including DC motors, solenoids, shape memory alloy linear actuators and micro-switches. Their initial ramp-up time on the BASIC Stamp was approximately 2 weeks, after which they were quite proficient with the units. Their design projects performed to all specifications, and met the expectations of the course. The two winning mechatronics designs are shown in Figs 7 and 8.

The overall competition was run with both mechatronics systems as well as mechanical systems. In the final rounds, the mechanical and mechatronic systems competed against each other, in a head-to-head fashion. The overall winner of the competition was a purely mechanical system. This result was due to two major reasons. First, the competition was tailored specifically for mechanical systems. Second, the groups using the mechatronic systems tailored their systems to compete against other mechatronic systems. Thus, they were substantially slower than the pure mechanical systems. In the end, the best mechatronic designs were basically mechanical designs augmented by mechatronics; rather than mechatronic systems augmented by a mechanical system. This achieves one of the course objectives, to promote mechanical design and augment with electronic systems. Clearly, if the mechanical design is not well

conceived and executed, a good mechatronic design component cannot offset this shortcoming.

Presently, the students' performance is being evaluated as we prepare for the expansion of the course to two sections of 20 students for the summer term and then the entire undergraduate mechanical engineering population (approximately 160 students) the following Fall semester. The Mark I EIS units will be employed this summer with some slight modifications (e.g. fuses) and the Mark II systems are scheduled to be in service for the Fall semester. The course will be run every semester (Fall, Spring and Summer) in the School of Mechanical Engineering, serving approximately 300 student per year.

As stated previously, the systems being developed at Georgia Tech are produced using standard techniques and technology that are readily transferred to other entities. Thus, other institutions interested in using the EIS as well as the actuators and sensors can readily produce these units at a reasonable cost. Within one year, it is anticipated that the Mark II EIS will be tested and fully debugged permitting the distribution of its design. Once an institution has this design, it will be possible for them to outsource the fabrication of the majority of the unit. In general it is quite easy and fast to have the PC boards produced and populated at a variety of companies. The final packaging of the EIS may have to be accomplished in house at the academic institution; however, this effort should be minimal.

Thomas R. Kurfess received his SB, SM and Ph.D. degrees in Mechanical Engineering from MIT in 1986, 1987 and 1989, respectively. He also received an SM degree from MI. in electrical engineering and computer science in 1988. He is currently a Professor in the George W. Woodruff School of Mechanical Engineering at Georgia Institute of

Technology. He presently serves as a participating guest at the Lawrence Livermore National Laboratory in their Precision Engineering Program. His research work focuses on the design and development of high precision manufacturing and metrology systems. He has also given a number of workshops, sponsored by the National Science Foundation in the area teaching controls and mechatronics to a variety of faculty members throughout the country.