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The Role of Mechanical Design in Mechatronics Education

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Abstract-- A survey of Mechatronics course offerings around the United States shows a rich variety of approaches to this topic.[1] Indeed, it appears that a majority of Mechanical Engineering programs across the country offer some formal offering in this area and it seems clear that the vast majority of Mechatronics courses are offered through Mechanical Engineering departments. With the traditional emphasis on design skill in mechanical engineering, it would seem obvious that mechatronics courses would feature a major design component. Surprisingly, very few existing mechatronics courses (at least those reported in the literature) feature a strong emphasis on mechanical design. That's is not to say that the creative process of design is not featured in Mechatronics courses, because it clearly is. It seems equally clear, however, that that accepted definition of mechatronics ("...the synergistic combination of mechanical engineering, electronics, control systems and computers..")[2] is not being adequately implemented in the classroom. This paper will address this issue, suggest probable reasons for it and describe a new course being developed at Boise State University which places a much stronger emphasis on mechanical design skills and practice than many mechatronics courses.

Index Terms—Mechatronics, Education

I. Introduction

Nearly everyone who has taught, or taken, an engineering course on the subject of mechatronics quickly comes to the same conclusion: The design and implementation of mechatronic systems is a highly satisfying process in which practitioners balance analytical skills with craftsmanship and creativity. There is undeniable fascination with the process of having a computer control a physical system. There is also a 'snowballing' effect that takes place over the course of a typical semester as students realize that they can understand much of the textbooks and popular books written in this area and therefore teach themselves. A mechatronics course with little or no mechanical design component can be highly rewarding, effective and appropriate. If this is the case however, the true potential of mechatronics is being missed.

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II. The Problem

While no one can argue that the creative process known as design is not an important part of nearly all mechatronics courses, there is very little of the traditional mechanical design experience incorporated into most of these courses. This is usually obvious by inspecting the resulting mechatronic projects. While some students are capable of designing and constructing aesthetically pleasing and reliable mechanical designs, these aspects usually take a back seat to the time intensive processes of circuit design, program organization and the debugging of both. In short, the design emphasis is on the electronics and the control program and the mechanical system being controlled (often purchased as a kit or as a unit) is considered a sideline – something on which to hang the electronics and microcontroller. Often, this is considered a reasonable tradeoff due to the large amount of material that can be covered in a mechatronics course. The issue is further complicated by the fact that the faculty members who usually engage in development and teaching the mechatronics courses are rarely those involved in mechanical design courses. Further, many lack formal training in mechanical engineering at all, coming instead from and Electrical or Systems Engineering background. The problem is a formidable one, but ripe for innovative solutions.

III. Mechatronics at Boise State

Boise State University, situated in a rapidly-growing high-tech corridor surrounding Boise, Idaho started a four-year engineering program in 1996 and an MS program in engineering in 2000. All three undergraduate programs (mechanical, electrical and civil) were accredited (under the old guidelines) by ABET in 1999. The college of engineering enjoys strong support from the state, the university and local industry. The college also enjoys a diverse faculty, many of whom have extensive industrial experience. The mechanical engineering curriculum was explicitly designed to have a very strong emphasis on mechanical design [3] and students who graduate from our program are eagerly employed both locally and across the nation.

In this context, a new course is being developed to train students in the art and science of mechatronics. The course

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is entitled: "Design and Analysis of Mechatronic Systems" and was offered for the first time in spring semester of 2001. In developing this course, the author has attempted to leverage the rich tradition in mechanical design present at BSU with his own experience teaching mechatronics at a large research-oriented institution over the past decade [4,5].

Two simple steps formed the foundation of the approach to achieve this goal. First, the lab was equipped with a set of bench-top tools and a selection of construction materials to encourage students to engage in the process of mechanical fabrication of their designs and second, the instructor regularly reminds the students of the important of aesthetics and craftsmanship in their work. This feeling is embodied in the mechatronics lab motto: "Just say 'NO' to duct tape!"

The result is a course with heightened expectations in mechanical design at the cost of reduced content in electronics issues, specifically in digital logic design and signal processing.

IV. Computational Platform

While the task of designing, assembling and operating a new mechatronics lab from the ground up is daunting, it is also an opportunity to re-assess decisions regarding software and hardware many of which are the result of compromises and institutional inertia. The choice of computer platform for the implementation of mechatronics designs is crucial and sets the tone for the rest of the course. The decision is informed by the personal experiences of the instructor(s) and must be modified by the culture from which the particular student body has emerged.

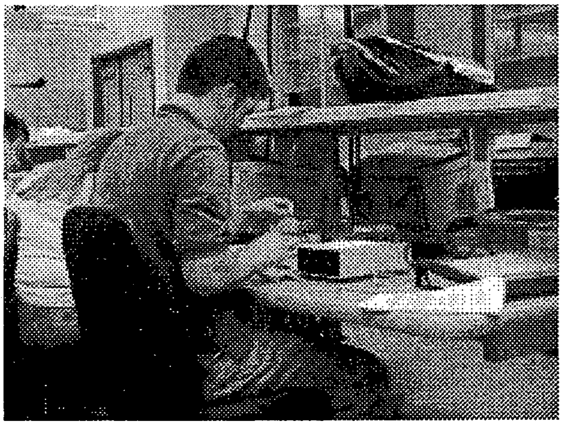

Figure 1: Typical workstation in the mechatronics laboratory.

In the case of Boise State Mechanical Engineering, formal computer programming is no longer included in the curriculum. It seems clear that any platform that required "C" or assembly language would not be an appropriate choice. On the other end of the spectrum, the "Basic Stamp" has opened a new era of embedded control, making this portion of mechatronics accessible to a large portion of the population, requiring only minimal knowledge of computer architecture and programming. However, experience with the Basic Stamp (and it's successors) has shown that it can be rather limiting for more interesting applications such as robot navigation and multi-process control. Slow execution speed (of interpreted BASIC), very limited analog I/O and no floating-point support are often sited as the major shortcomings.

Few fields of endeavor are evolving as quickly as microelectronics and new products seem to appear monthly. One recent addition to the array of microcontroller products is the BX-24 system, based on the Atmel AT90S8535 microncontroller. The BX –24 is manufactured by Net Media and can be purchased separately, or in a development kit consisting of a BASIC compiler, RS-232 cable, power supply and a full set of documentation on CD ROM.

The main features which make the BX-24 attractive are the ample program memory (enough to hold the compiled equivalent of about 8000 lines of BASIC code), on-board A/D converter with 8 SE inputs, floating point support and the fact that the programs are compiled (on a PC) and downloaded as native code. The resulting platform is one with a fairly simple architecture, very fast operation and capable of running sophisticated numerical-based algorithms.

The typical workstation is completed with the following equipment:

- Infinium digital oscilloscope (also a Windows PC)
- Powered electronic protoboard
- Digital multi-meter
- Assorted hand tools

V. "Design-Friendly" Laboratory

To create an environment which would encourage the application of mechanical design principles, the laboratory has a few pieces of equipment that are not typically found in a mechatronics lab as shown in Figure 2. A small drill press, band saw and belt sander are installed along one wall in the lab. While this causes some problems due to noise and dust, the convenience of having the equipment in the same room as the electronics prototyping is an extremely important factor in having the students engage in good mechanical prototyping practices.

Since the presence of metal shavings and chips(that inevitably arise in the processing of metal) pose serious hazards to electronic equipment, students in the class work mostly with plastic and hardwoods for mechanical prototyping thus minimizing the detrimental impact of conductive debris.

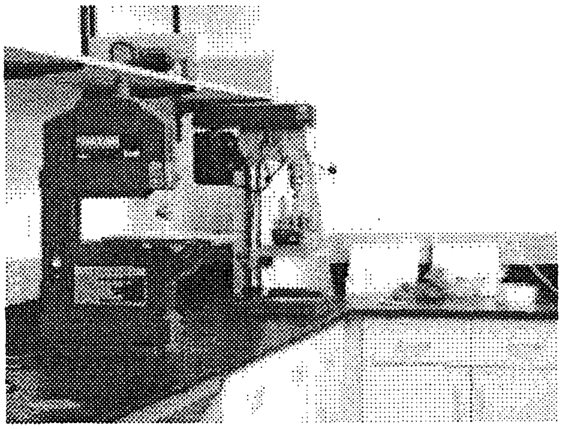

Figure 2: The mechanical fabrication portion of the Boise State Mechatronics Laboratory

VI. RESULTS FROM LABORATORY EXPERIMENTS

The curriculum is structured in a manner that is similar to most mechatronics courses. The lectures on digital circuits, op-amps and signal processing are complemented by a series of 4 pre-defined laboratory experience during which the students apply their knowledge of electronic circuits and computer programming. Figure 3 shows typical results for Lab #2 in which the students interface an LM 35 temperature sensor with the BX-24 and then display the results on a 2-digit 7-segment display. The display alternates between Fahrenheit and Celsius scales.

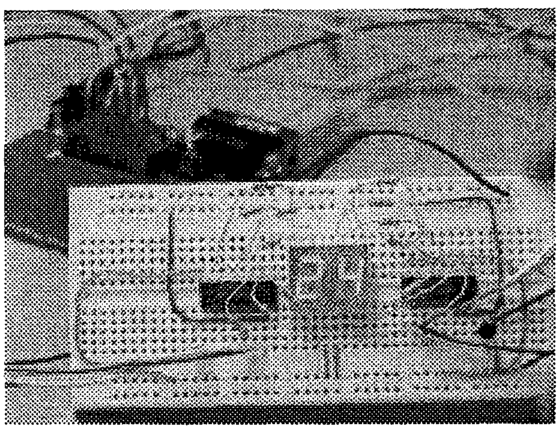

Figure 3: Typical results from Lab #2: A digital thermometer. The BX 24 controller is visible in the background

After several weeks of focusing on the electronics circuit and design, the students are assigned a more open-ended task. They are instructed to build a device, which will scan around a full circle, locate the brightest light in the room and follow that source as it moves. Figure 4 shows the schematic depiction that demonstrated the concept on the lab instruction handout [6].

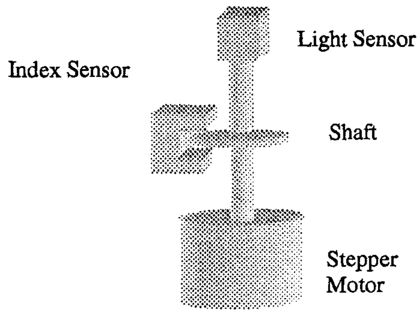

Figure 4: Schematic diagram of light tracker as shown to the students in the original handout.

Note that the students were asked to incorporate a sensor that would allow the system to initialize itself at power-up and thus be capable of reporting the bearing of the light source in absolute coordinates.

Figures 5 and 6 show two typical design solutions that the students created. Note that the students made efforts to securely mount the stepper (and make room for the second shaft), construct a shaft and incorporate the light sensor.

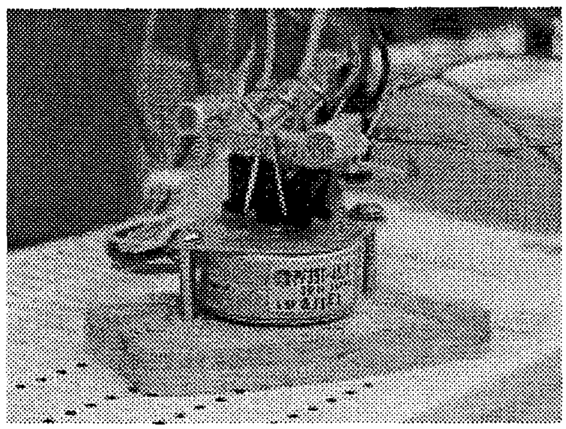

Figure 5: Typical light tracker. Note that the initialization sensor is partial obscured behind the devices left 'eye'.

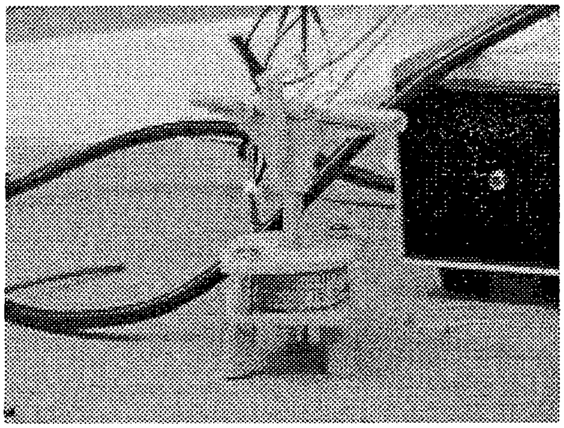

Figure 6: Another typical response to the problem. At the time this photo was taken, the indexing sensor has not yet been installed (see Figure 7)

Figure 7 shows a close up of the indexing sensor that was implemented for the design shown in figure 6:

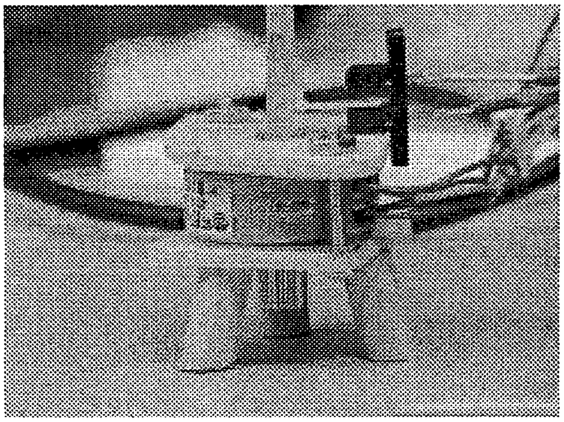

Figure 7: Detail view of the index sensor.

It's important to note that, while the obvious solution for an indexing sensor is to have a disk with a single hole in it's periphery, the students found other solutions that were easier to fabricate with the items at hand. In this manner, they were directly exposed to, and benefited from, lessons in design for manufacture.

Figure 8 shows the detail of yet another design for the indexing sensor, again showing a simple, efficient and easy to fabricate implementation.

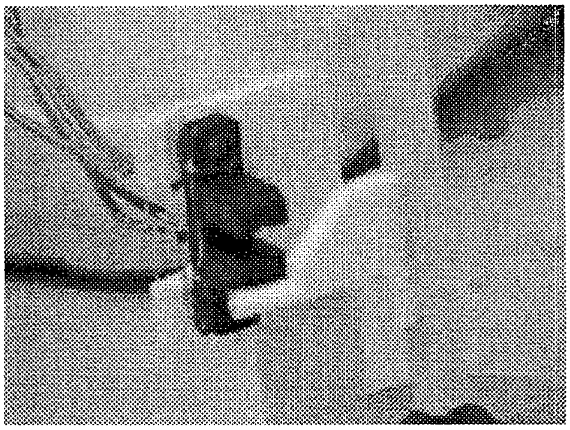

Figure 8: Detailed view of another initialization sensor

Finally, Figure 9 shows a particularly ingenious sensor for the light tracker. Three light sensing elements are incorporated to improve localization and dynamic tracking performance. In addition, the designers have solved the problem that vexed many of their colleagues. The wire used to connect the sensors to the BX 24 was getting wound up around the shaft of the system, leading to intermittent connections and high loads on the stepper motors. The students got around that problem by using a rotating connector (available from most stores that carry telephone accessories). The slip ring fixture made for a much cleaner design.

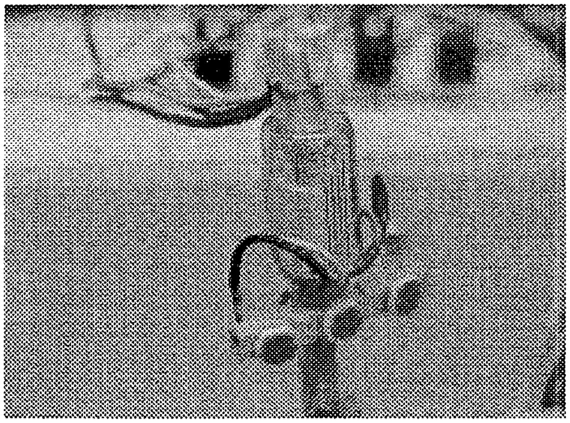

Figure 9: Implementing a telephone slip ring connector to de-couple the light sensor lead wires from the tracker's motion.

VII. MECHATRONICS PROJECT

The light tracker experiment reported in the previous section was complete shortly after the 8th week of a 15-week semester. The remainder of the semester is taken up by a project. The students were told to design, construct, and operate an autonomous robot that was capable of moving about a confined area (like the hallway of a classroom building). Somewhere in that area is a small beacon that is flashing an infrared LED at a prescribed frequency. The goal was to race another robot to the beacon, deposit a ping-pong ball at the beacon and return to the starting location. They robots would compete in a double-elimination tournament to find a winner. As is often the case with such competitions, active interference with the competitor (eg by flashing their own IR beacon) is allowed, if not outright encouraged.

In order to avoid the situation in which the students hastily assemble a random assortment of parts in the day or two immediately prior to the competition, a series of one-page reports were due throughout the second half of the semester. These reports served as milestones in the design process. The reports outlined progress in the following areas of the design process.

1. Robot kinematics (number of wheels, type of steering)
2. Motor and dive system design (type of motor and transmission(s)
3. Batter selection (NiCd, Pb-acid, etc.)
4. Program architecture

Figure 10 shows the chassis of one of the vehicles from the class.

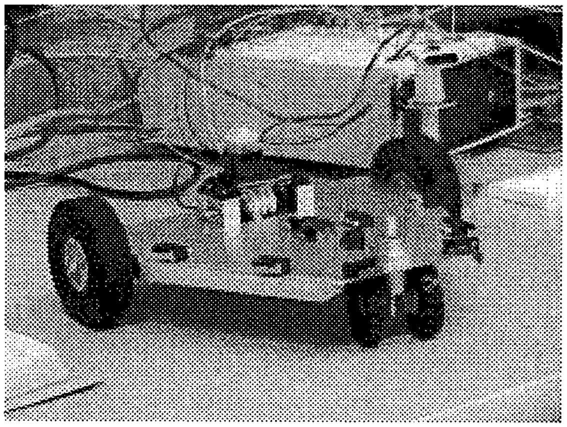

Figure 10: Chassis for three-wheeled autonomous robot in the early stages of construction.

VIII. RESULTS

The course was offered for the first time in the Spring semester of 2001. At the time of this writing, the course is 4 weeks from completion, but certain observations can be reported. The students responded very positively to the presence of light fabrication machinery in the lab. Many report that this is the kind of course they've been wanting to take for the four years they've been in engineering school. Also, the mini-reports leading up to the competition appear to have been a very useful tool in bringing the students through the design process by explicitly spelling out some of the major design decisions that lie along their paths.

The course fits in nicely to Boise State's curriculum, which requires that all Mechanical Engineering students take at least on elective that has been designated a 'design' elective by the faculty.

Finally, the class has already caught the attention of engineers and managers from local industry, largely because many of the students work full-time or part-time in engineering offices throughout the region. It is hoped that this will lead to better interactions and support from the local companies.

IX. ACKNOWLEDGEMENTS

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