

Development of a Mechatronics Design Studio

Sema E. Alptekin
Industrial and Manufacturing Engineering Department
Cal Poly, San Luis Obispo

ABSTRACT

Mechatronics is a combination of mechanics, electronics and information technology intended to raise the intelligence level and flexibility of products and devices. There is a need to develop programs and laboratories in Mechatronics to create an understanding of how new technologies influence the traditional methods of designing products and manufacturing systems. A model "Mechatronics Design Studio" has recently been developed to support the Mechatronics and Manufacturing Automation courses offered at Cal Poly's Industrial and Manufacturing Engineering Department. Laboratory experiments have been developed and several student projects have been completed. In this paper, an overview of the design studio and select student projects is provided.

I. INTRODUCTION

Mechatronics is a combination of mechanics, electronics and information technology intended to raise the intelligence level and flexibility of products and devices (Salminen et al). There is a need to develop interdisciplinary programs in Mechatronics. The interdisciplinary nature of the IME Departments provides a natural home for Mechatronics programs. Development of a Mechatronics focus within Cal Poly, San Luis Obispo's Industrial and Manufacturing Engineering (IME) program is underway. A model "Mechatronics Design Studio" has recently been developed to support the Mechatronics and Manufacturing Automation courses and course modules offered at the IME Department. Our approach to the development of Mechatronics focus is presented in section II. Select student projects are documented in section III followed by an overview of the Mechatronics Design Studio in the last section of the paper.

II. MECHATRONICS FOCUS

Several courses are being modified and new course modules in Mechatronics are being developed within Cal Poly, San Luis Obispo's Industrial and Manufacturing Engineering program in order to create a better understanding of how new technologies influence the traditional methods of designing products and manufacturing systems. While the lower-level courses introduce the concept, the upper-level courses provide opportunities to gain expertise in special areas of Mechatronics (Figure 1) (Alptekin and Freeman). Several projects integrate the courses offered at the different levels of the curriculum. The design and manufacturing laboratories of the IME Department are utilized in the design and development of these products and systems. The following courses utilize the Mechatronics Design Studio that is the topic of this paper: IME 101: Introduction to Industrial and Manufacturing Engineering, IME 356: Manufacturing Automation, IME 416: Automation of Industrial Systems, and IME 516 -- Mechatronics Systems Analysis.

A 2-week Mechatronics module has recently been developed and implemented in IME 101 (Introduction to Industrial and Manufacturing Engineering). This module is designed to introduce Mechatronics concepts at the early phases of the program and hopefully create excitement among

our students. Six laboratory stations have been developed utilizing the Mini Board (Martin 1994-1) and Fischertechnique components. The students visit these stations and answer questions during the first week. They build and program a simple car during the last week of the module which is explained in Section III.

IME 356 Manufacturing Automation course provides an overview of the building blocks of automation -- sensors, stepper motors, actuators, robots, vision systems, programmable logic controllers, and communication networks. A seven-station automation laboratory affords students the opportunity to work with industrial-grade equipment and to apply theoretical concepts introduced during formal lecture sessions. Undergraduate students learn how to:

- program robots to accomplish tasks,
- design a pneumatic circuit to sort parts,
- write a ladder logic program to move ping-pong balls between various points, and
- develop a C program to control stepper motors based on input received from different sensors.

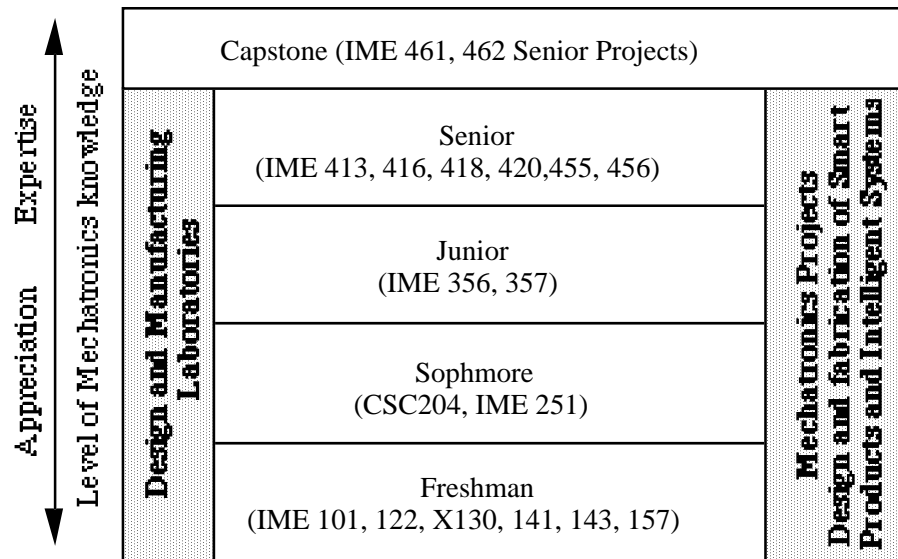


Figure 1. Integrated Curriculum

Our ultimate goal in this class (IME 356) is the synergistic fusion of these "Building Blocks" into a Mechatronics strategy to design, build, and control smart products by the end of the quarter. The students are asked to design and build a prototype smart product as their term project. Use of similar projects to motivate student learning have been reported in literature (Sasaki et al.; Martin 1994-2; Carryer 1994-1; Auslander et al., Carryer 1994-2). Our approach is reported in an earlier paper (Alptekin 1995).

In IME 416 Automation of Industrial Systems, the follow-up course of IME 356, the students integrate their IME 356 projects and other devices such as robots into a flexible system (see Section III for sample projects). The emphasis in this course is the integration of components into a whole. They learn about how to integrate these islands of automation into an automated system. A term project ensures that the students gain hands on experience while working as a member of a team. This is usually an open-ended project limited by the equipment and budget available for this course. The course prepares the students to work as members of a team and helps them realize the advantages/limitations of teams in accomplishing large integration projects.

IME 516 -- Mechatronics Systems Analysis is a graduate level course and builds on the knowledge gained in the prerequisite courses (IME 356 and IME 416). Case studies explaining how new technologies are utilized in the design, manufacturing, and operation of smart products and intelligent systems and advanced topics in Neural Networks and Fuzzy Logic are covered. The term project focuses on adding intelligence to the projects developed in the prerequisite courses.

Documentation of several student projects is provided in the next section. These projects are also documented at <http://www.calpoly.edu/~salpteki>. An overview of the Mechatronics Design Studio is summarized in the last section of the paper.

III. STUDENT PROJECTS

Class projects that motivate student learning are an important part of our program. One popular project is to design and build a car that would perform certain tasks.

30 Minute Car: The car in figure 2 is used during the first session of the Mechatronics module in IME 101 (Introduction to Industrial and Manufacturing Engineering). The students are given a partially completed C program, a Mini Board, and a kit containing components that they will need in order to build this car. Among these are a stepper motor and an infrared photo detector ready to be inserted into the Mini Board.

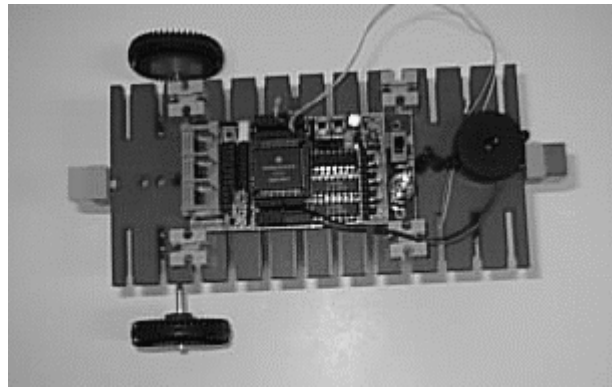
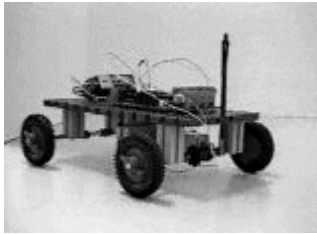


Figure 2: 30 Minute Car

A working model is also provided to help them visualize the finished product. It also helps them finish the project in a limited amount of time (30 minutes). They are asked to work on this project as a team of four. They first work as design engineers putting together the mechanical components of the car. They then perform programming tasks -- typing in the missing lines of a partial C program, compiling and downloading it to the Mini Board. This car moves forward if a flash-light is directed toward its sensor, and stops if the light source is turned off. Having multiple teams working simultaneously, and demonstrating their cars at the end of the session creates great enthusiasm.

Bumper Car: The project shown in Figure 3 was built by Cal Poly students as their class projects in IME 356 Manufacturing Automation course in the Spring of 1996. This car has

sensors hidden behind its bumper which cause the car to change its direction if there are any

barriers in its way (Mallari and Kotsubo). In the Fall of 1996, the same project was used as one of the six stations to introduce Mechatronics in IME 101. This method of laboratory development -- utilizing student projects from upper levels at the entry level has been found to be very efficient.

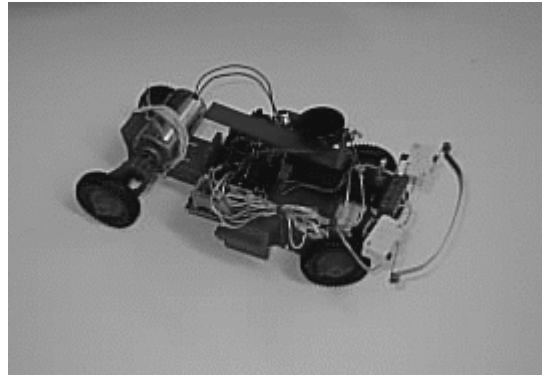


Figure 3: Bumper Car

The Goal: The project shown in Figure 4 -- the "Goal" was designed and built by three Mechanical Engineering students (Gray et al.). In the design of this car, small size was one of the constraints. The idea was borrowed from the Micro-Robot World Cup Soccer Tournament held in Korea. This tournament was funded to promote the development of small, autonomous robots and intelligent systems that can cooperate with each other (KAIST). The "Goal" consists of a 11.5 cm x 11.5 cm x 7 cm plexiglass chassis that houses: two 3.6 degree stepper motors, a Mini Board -- Motorola M68HC11 based control unit, two nine volt batteries, and a hand-held control unit to control the speed and direction with an attached potentiometer and the touch key pad.

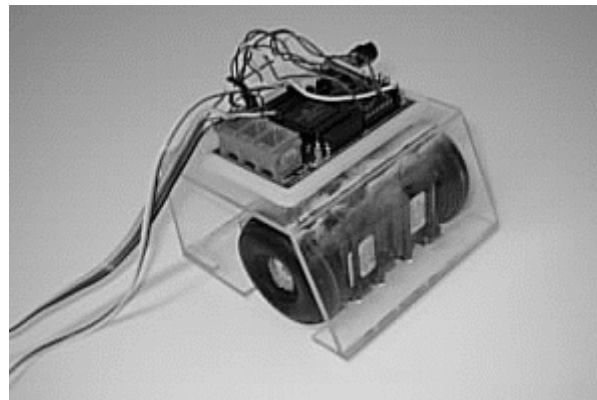


Figure 4: The Goal

The Flexible Cell: The Goal was integrated into a Flexible Cell as IME 416 term project in Fall of 1996. The students were asked to design and build a flexible system (Figure 5) that would be demonstrated during several campus activities. The automated system demonstrates the loading of widgets by a robot arm onto the Automated Guided Vehicle (AGV) -- a simpler version of the Goal explained above. The AGV is directed to designated assembly stations, then activated to move until the appropriate location sensor is tripped and loaded by the robot. This fully integrated system completes all actions without any assistance, but that of the commands entered by the user into the computer that simulates process routings. The system demonstrates

flexibility by being able to send the AGV and the robot to any assembly station following the process routings entered by the user on-line. This flexible system consists of the following elements:

- A SCARA Robot (IBM 7547)
- In-house built AGV
- Three assembly stations
- Cell controller
- Mini Boards (Mini Board I as the AGV controller, Mini Board II as the sequencer).

The major tasks in the development of this cell were:

- Design of the overall system and design of control hierarchy,
- Design, build, and program the AGV: Evaluation of sensor-light source pair, flow chart of the program, mechanical design of the AGV.
- AML program: Development of the AML program that reads input values and branches to different subroutines to load the AGV at the selected station.
- Q-basic program: Development of a user-friendly program to allow the user to define a sequence of assembly stations that the AGV visits to be loaded by the robot. Example: 3-1-2
- Documentation (Hard copy and home page development): Each member contributed to the final report. As subsystems were developed, the work was documented. The final report was prepared in the form of a paper that won the first place at the Institute of Industrial Engineering Student Conference that was held at Cal Poly in February 7-9, 1997 (Kadlecek et al.). A web page (<http://www.calpoly.edu/~ime400p1/mech/studentproj/ime416/ibmcell.html>) documenting the details of the project was also prepared. The Q-Basic program controls the relays that are part of the IBM robot's interface panel. The user-interface allows the user to input the process plan. This process plan shows the sequence of stations that will be visited by the AGV system. Example: 3-1-2 will send the AGV to station 3 first, then to 1, and finally to station 2. This then will be sent to Mini Board II via a serial cable. The Mini Board II will then interpret the information from the Q-Basic program and decide which relay to turn on.

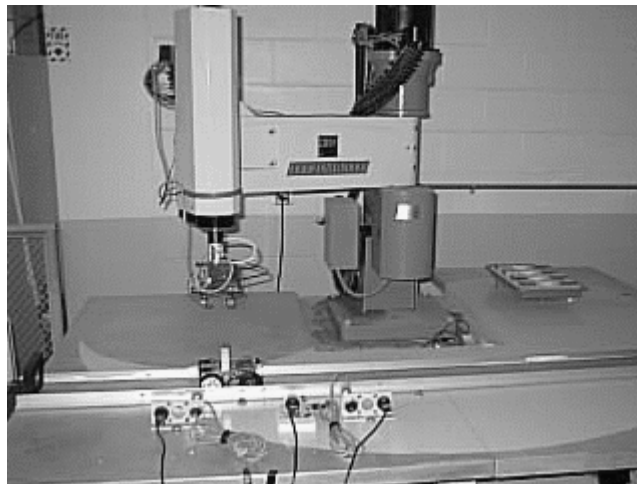


Figure 5: Flexible Cell

Once the relay is switched on, the AML program takes over and decides what to do. The AML program first turns on the appropriate directional light (track light) to direct the AGV in the proper direction. The AGV is equipped with two light sensors, one in the front and one in the

back. The inputs received from these sensors are used by Mini Board I to decide whether to move the AGV forward or backward. When the appropriate location sensor is tripped by the AGV, the directional light is turned off. When the light is turned off, the AGV stops. The IBM robot then steps into action by loading the AGV with the appropriate part. Once the part is loaded, the IBM robot sends a response to an output on the interface box that is hooked up to Mini Board II.

The Mini Board then sends a signal to the Q-Basic program saying that the motion has been completed. Now that the motion has been completed, the Q-Basic program sends the next command to the Mini Board II. The Mini Board II then sends a signal to a relay on the IBM interface board. The AML program takes this information and decides whether to send the AGV to the next position or to send it to its home position. This looping of events continue until there are no more instructions left that are sent from the Q-Basic Program.

The Automated Guided Vehicle: The AGV is designed as a simple smart product that will interface with a series of sensors that will tell the AGV where to go and what to do. The AGV is equipped with two light sensors, one in the front and one in the back (Figure 6). The inputs received from the sensors are used by the Mini Board I to process and to decide whether to move the AGV forward or backward. The limit switch mounted in the rear is used to stop the AGV once it has finished following the sequence of the process plan. The switch is pressed when the AGV is directed by the rear light sensor directly into the wall at the end of the track.

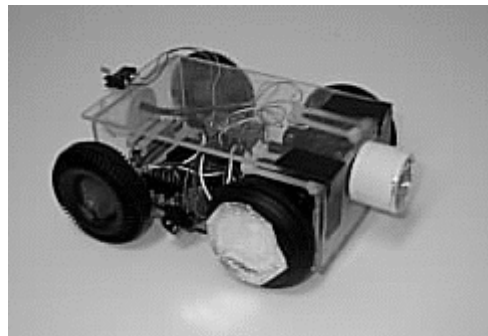


Figure 6: Automated Guided Vehicle

The AGV is comprised of the following components:

- Plexiglas chassis
- Two 3.6 degree stepper motors
- Motorola 6811 Mini Board
- One limit switch
- Two photo resistors
- 2 nine volt batteries as power source.

The Mini Board II: The Mini Board II is used as a integration interface program between the Q-Basic program and IBM Robot's AML program. Mini Board II becomes very much the sequencer to the Front-End Q-Basic program (which take the user inputs) and the Back-End AML program that directs the lighting, sensors and the movement of the IBM robot in the Flexible Cell system. Mini Board II receives one Q-Basic signal via serial cable. Mini Board II interprets the signal from the Q-Basic program, Mini Board II takes in the Q-basic program input of either 1,2, or 3. The Q-basic program input is in ASCII Format. Mini Board II than sends a signal to the

Technovate Control Panel (In ports 2,3 or 4). Mini Board II activates the relay that is to be turned on the Technovate Control panel. Once a selected relay is on, the AML will direct the next step of activities.

IV. MECHATRONICS DESIGN STUDIO

A model "Mechatronics Design Studio" has recently been developed to support the Mechatronics and Manufacturing Automation courses and course modules offered at the IME Department.

The objective is to provide the students with a suite of design and ready-to-assemble modules to enable them to concentrate on the design issues without becoming mired in the implementation of the electronic, mechanical and software components of the product. The following is a list of major components that should be included in a Mechatronics Design Studio:

- 1) Building blocks of mechatronics (i.e. sensors, actuators, microprocessor based controllers, control software, mechanisms, etc.),
- 2) Documentation on how to choose the right components for a project (previous student projects, video clippings of previous work, vendor catalogs, etc.),
- 3) Lab experiments exploring smart and mechatronic products,
- 4) An integrated environment to design and rapidly prototype smart products.

The following items have been procured and developed as part of items #1, 2 and 3 above:

- Microprocessor based controller Mini Board (Martin 1994-1)
- C compiler -- ICC11, Source: Image Craft, P. O. Box 64226, Sunnyvale, CA 94088-4226
Phone: (408) 749-0702
- Fischertechnik kits, Source: Creative Learning Systems, Inc., 16510 Via Esprillo, San Diego, CA 92127-1708, Phone: 1-800-458-2880

- Industrial grade sensors and motors

Sources: Compumotor, 5500 Business Park Drive, Rohnert Park, CA 94928, (800)-358-9070.
DigiKey, <http://www.digikey.com>, Phone: 1-800-344-4539

Marlin P. Jones & Assoc., P. O. Box 12685, Lake Park, FL 33403-0685, (800) OK 2 ORDER

- Embedded Controllers

Source: Ziatech, 1050 Southwood Drive, San Luis Obispo, CA 93401, Phone: (805) 541-0488

- Programmable Logic Cont., Source: Allen Bradley, 5836 Corporate Ave. Cypress, CA 90630

Textbooks and catalogs:

- The Mini Board 2.0 Technical Reference by Fred G. Martin, Media Laboratory at the Massachusetts Institute of Technology 20 Ames Street Room E15-320, Cambridge, MA 02139.
e-mail: fredm@media.mit.edu
- M68HC11 Catalogs, Source: Motorola Literature Distribution P.O. Box P.O. Box 20912, Phoenix, AZ 85036 (800) 521-6274
- Understanding Electro-Mechanical Engineering, An Introduction to Mechatronics, Lawrence J. Kamm, IEEE Order No. PP3806-QEG, ISBN 0-7803-1031-4
- Electro-Mechanical Engineering, An Integrated Approach, C. Fraser and J. Milne, IEEE Order No. PC5610-QEG, ISBN 0-7803-1142-6.
- Mechatronics, Bradley, Qawson, Burd, Loader, Chapman Hall, 1991, ISBN: 0412582902.
- The C Programming Language, B. W. Kernighan and D. M. Ritchie, Prentice Hall Software Series, ISBN 0-13-110362-8

- The Robot Builder's Bonanza: 99 Inexpensive Robotics Projects, TAB Books, Gordon McComb, 1987
- Design with Microprocessors for Mechanical Engineers, Stiffler, K., Mc Graw Hill Series in Mechanical Engineering, 1992.
- Mechatronics - Electronic control systems in Mechanical Engineering, W.Bolton, Longman 1995, softcover, 0-582-25634-8.
- Microcomputer Control of Thermal and Mechanical Systems, W.F. Stoecker and P.A. Stoecker, 1989, Van Nostrand Reinhold book, ISBN 0-442-20648-8.
- Mechatronics, Mechanical System Interfacing, David M. Auslander and Carl J. Kempf, Prentice Hall, 1996, ISBN 0-13-120338
- Mobile Robots: Inspiration for Implementation, Jones and Flynn, Published by AK Peters, Wellesley, MA ISBN 1-56881-011-3.
- Controlling the World With Your PC, Paul Bergsman, HighText Publications Inc., Solana Beach, CA 92075, ISBN 1-878707-15-9.

V. CONCLUSION

Any Mechatronics curriculum that is implemented, should be supported by instructional experiments and teaching modules developed by a team of interdisciplinary faculty members. These modules prepare graduates with the skills required to design, fabricate, build, and operate smart products and intelligent systems. One of the goals of the Synthesis Coalition -- a project supported by NSF which involves the following eight institutions: Cal Poly, Cornell, Hampton, Iowa State, Southern, Stanford, Tuskegee and UC-Berkeley -- is to produce innovative curriculum structures and instructional delivery systems for undergraduate engineering education. Mechatronics has been targeted as one of the areas to be addressed by this coalition. Some of the projects documented in this paper were among our deliverables as a member of the coalition. Other results of Synthesis supported work can be found at <http://www.needs.org/>. Similar coalitions and interdisciplinary projects are laying the foundation that will eventually lead to successful Mechatronics curricula.

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SEMA E. ALPTEKIN, Ph.D.

Sema Alptekin is a Professor at the Industrial and Manufacturing Engineering Department of Cal Poly, San Luis Obispo where she teaches Manufacturing Automation, Mechatronics, and Production Control. She holds a B.S. and an M.S. in Mechanical Eng., and a Ph.D. in Industrial Eng. from Istanbul Technical Univ., Turkey. Her experiences include working for the University of Missouri-Rolla and General Motors. She is a member of ASEE, SME, and IIE.