The Vertical Integration of Mechatronics at Virginia Tech

by

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To Dottie & John

The Vertical Integration of Mechatronics at Virginia Tech

Abstract

The focus of this thesis is on the vertical integration of mechatronics in the mechanical engineering curriculum at Virginia Tech. It reports the details of an experimental strategy to integrate mechatronics at an early level in the education of engineers. A proposal was submitted to and accepted by the NSF/SUCCEED coalition to fund this experiment. Through this assistance, the experiment of vertically integrating mechatronics was initiated. The methodology in which it was integrated is presented -- through optional participation in a sophomore design class and a required design project in a junior system dynamics course. The material developed for the vertical integration of mechatronics is in the appendices. This material is appropriate for other institutions to use to vertically integrate mechatronics into their curriculums, which is part of the NSF/SUCCEED coalition's initiative.

For the sophomore class, ME 2024, Introduction to Engineering Design and Economics, selected sections were exposed to the concepts of mechatronic design, along with the normal course material. Students in the mechatronic sections were given an opportunity to incorporate the use of a custom-built VT Project Box and the PIC Visual Development (PVD) software, both of which were created specifically for the task of vertical integration of mechatronics. Throughout the semester, the students were given several demonstrations of mechatronic systems through the use of the project box and software. Many students decided to implement mechatronic concepts in their final design projects. A smaller number of students made a decision to use the project box and software to develop a prototype of their final design project. Candid remarks about the students experiences, obtained from a survey at the semester's end, indicated that the vertical integration of mechatronics was a motivational feature in the second-year curriculum.

For the junior class, ME 3514, System Dynamics, all sections were exposed to the concepts of mechatronics, along with the normal course material. The students were required to acquire steady-state velocity data from a DC motor and create an analytical model of the motor to predict the steady-state velocity for a given duty cycle of a pulse-width modulated controller. After the collection of the data and the creation of the analytical model, the students compared the results of simulations to the actual data collected, and report the comparison to the instructor in a memorandum. The collection of the steady-state velocity data was accomplished using the PVD software and the VT Project Box. The essentials of mechatronics was communicated to the students in two lectures, and the students gained hands-on experience with mechatronics through the use of the project box and the software. The lecture material covered the basics of mechatronics, the Mechatronics course at Virginia Tech, and detailed information about the design project. The assessment of the vertical integration of mechatronics into this junior course was accomplished by surveying all of the students in the course. The results of the survey indicated that the inclusion of mechatronics material increased the students understanding of the course material and also increased their interest in mechatronics.

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Donald E. Grove

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V_a Armature voltage

L_a Armature inductance

i_a Armature current

R_a Armature resistance

V_b Back-emf voltage

K_b Back-emf constant

$\dot{\theta}$ Motor shaft angular velocity

$\ddot{\theta}$ Motor shaft angular acceleration

J Shaft inertia

b Friction term

K_T Torque Constant

s Laplace variable

G_m Motor transfer function

Chapter 1

An Introduction to Mechatronics and the Concept of Vertical Integration

1.1 Introduction

In the past decade, the need for mechanical and electrical engineers to be able to utilize basic skills of each other's discipline has become increasingly important. It has become such a necessity that many educational institutions now include a senior-level technical elective covering this subject matter. Virginia Tech is one such university that offers a course in *mechatronics*. This is, however, only one course on a subject that bridges four-year curriculums. The digital age we are experiencing dictates that, for engineering to prosper as a discipline, we must acquire a broader set of skills. For example, mechanical engineers must be able to use microprocessors and many other of the traditional electrical engineer's tools. For this to occur, mechatronics needs to be sufficiently integrated in the curriculums. Therefore, a vertical integration of mechatronics in the Mechanical Engineering Department curriculum was proposed to begin this process. Through assistance provided by NSF/SUCCEED, an experiment to vertically integrate mechatronics at an earlier level in the mechanical engineering curriculum was initiated. The fundamental purpose of this proposal was to introduce the essentials of mechatronics at an earlier academic level in the curriculum. The experiment was conducted from May of 1999 to December of 2000, and the integration was implemented in two separate courses, one at the sophomore level and the other at the junior level. Before it is possible to describe the task of vertically integrating mechatronics, it is helpful to define mechatronics and the role of vertical integration. In describing the vertical integration of mechatronics, it is also helpful to discuss the mechatronics curriculum at Virginia Tech and other schools. By examining what is taught at Virginia Tech and other higher education institutions, it will become clearer what can be taught to sophomores and juniors before they are eligible to enroll in the mechatronics course.

1.2 Defining Mechatronics

In the broadest sense, mechatronics is the combination of design principles in the fields of mechanics and electronics. This combination of design philosophies has existed under the name of mechatronics for nearly thirty years now, and was first called this by the Japanese engineers in the late sixties. "Mechatronics was first used in terms of computer control of electric motors by an engineer at Japan's Yaskawa Electric Company... The word has remained popular in Japan and has been in general use in Europe for many years (Ashley)." Mechatronics is not straightforward to define and has different definitions depending on the source. In this section, several definitions of mechatronics are presented inding one proposed by the author. A more inclusive list of definitions can be found at:
http://www.engr.colostate.edu/~dga/mechatronics/definitions.html. A few of the many definitions found in the literature follows:

Shetty and Kolk's definition:

- Mechatronics is a methodology used for the optimal design of electromechanical products.
- The mechatronic design methodology is based on a concurrent, instead of sequential, approach to discipline design, resulting in products with more synergy.
- A mechatronic system is not an electromechanical system and is more than a control system.
- The mechatronic system is multi-disciplinary, embodying four fundamental disciplines: electrical, mechanical, computer science, and information technology

Hsu and Wang's definition (San Jose StateUniversity):

- Mechatronics is an engineering process that involves "the design and manufacture of intelligent systems or products with hybrid mechanical and electronics functions."

Histand and Alciatore's definition:

- Mechatronics is an interdisciplinary field of engineering that deals with the design of products whose function relies on the synergistic integration of mechanical, electrical, and electronic components connected by a control architecture.

In the May 1997 edition of Mechanical Engineering Magazine, Ashley discussed mechatronics. In this article two academics and a mechanical engineer from industry gave their definition of mechatronics. Takashi Yamaguchi of Hitachi defined mechatronics as "a methodology for designing products that exhibit fast, precise performance. These characteristics can be achieved by considering not only the mechanical design but also the use of servo controls, sensors and electronics." Giorgio Rizzoni, associate professor of mechanical engineering at Ohio State University in Columbus, defined mechatronics as "the confluence of traditional design methods with sensors and instrumentation technology, drive and actuator technology, embedded real-time microprocessor systems and real-time software." He also said mechatronic products have distinguishing features, replacement of mechanical functions with electronics, that allow greater flexibility than the original system. Then, Masayoshi Tomizuka, professor of mechanical engineering at the University of California, Berkeley stated that, "mechatronics is really nothing but good product design practices," and " the basic idea is to apply new controls to extract new levels of performance from a mechanical device. This means using current technology to improve the product in cost, performance and flexibility."

The author considers mechatronics to be a design philosophy where the mechanical, electrical, control, and communication systems have been considered equally in the entire design process, from the conceptual design to final design. This means the resulting product is not more intelligent like Hsu and Wang state, and not necessarily optimal like

Shetty and Kolk claim. Histand and Alciatore define mechatronics as a field of engineering and not a design philosophy and they also consider the control system to be a piece connected to the system instead of part of "synergistic integration." Though there are differences in the definitions there are also similarities. All authors agree that mechatronics inherently means concurrent design, versus sequential, mechatronics is multi-disciplinary in nature, and is truly a good product design philosophy. In order for this design philosophy to move into industry (especially American industry) it must be an area of instruction at institutes of higher education. In the following section, mechatronics programs at various institutes are presented.

1.3 Mechatronics Programs at Higher Education Institutes

Four university mechatronics programs are presented in this section. All of the courses described are intended for undergraduate enrollment. The courses that are described include MIT's mechatronics course, Rensslaer Polytechnic Institute's two-course sequence in mechatronics, Georgia Tech's undergraduate level course in mechatronics titled Microprocessor Control of Manufacturing Systems, and Penn State's Microcomputer Applications (Mechatronics) course is presented. Also, in the following section, Virginia Tech's program is presented. These schools represent a good sampling of the current mechatronics curriculums offered in the United States. Several websites that provide links to various institutes and other mechatronics related material are the following:

www.mechatronics.org

http://www.engr.colostate.edu/~dga/mechatronics/links.html

1.3.1 Mechatronics at MIT

Trumper and Ludwick's paper describes the development and delivery of mechatronics at MIT. Mechatronics at MIT is centered around the lab experience, where controls, electronics and mechanics are integrated. There are many different goals set for the students in this course. The goals for the course include the following

- Proficiency with the lab equipment
- Develop analytical modeling skills
- Basic analog circuit design
- Introduce digital logic
- Interpret second-order system responses in time and frequency domains
- Understand sampling, aliasing, and quantization
- Digital equivalents to continuous controllers
- Brush and brushless motor design and control
- Understand common sensors in motion control
- Interconnections of electrical, mechanical, and control design in mechatronic systems

The labs are PC-based and D-Space hardware is used in conjunction with MATLAB and SimuLink. The reason for using the digital signal processing based hardware (D-Space) and block diagram programming (SimuLink) environments is to eliminate low-level programming and allow the students to concentrate on the higher level tasks. There are five laboratory experiments the students complete throughout the semester. The experiments completed include the following:

- Current control in a power inductive load
- Motor control
- Digital electronics
- Quadrature decoder
- Floppy drive disassembly

The labs are completed individually to ensure each student learns every lab. The students' performances are then evaluated using a one-on-one interview with a staff member, along with a lab report. The two lecture hours per week are used to support the laboratory activities. The course website is http://me.mit.edu/2.737/.

1.3.2 Mechatronics at Rensselaer Polytechnic Institute (RPI)

Mechatronics at Rensselaer is a two course senior-elective sequence. The first course is Mechatronics and the second course is Mechatronic System Design. The courses are based on the physical understanding of systems considered during the semester. In both courses five areas are emphasized:

- Mechatronic system design principles
- Modeling analysis and control of the dynamics of the physical system
- Selection and interfacing of sensors, actuator, and microprocessors
- Analog and digital control electronics
- Real-time programming for control

In the Mechatronics course, the fundamentals listed above are covered through the lecture and laboratory. In the Mechatronics System Design course, applications and extension of mechatronics, advanced topics relating to mechatronics, and in-depth coverage of the above areas are considered. The applications, extensions, and advanced topics include Fuzzy Logic, and smart structures. There is also more in-depth coverage of digital controls. The focus of the courses is kept on the role of mechatronics in the overall design process. The courses are designed around interactive learning. The interactive learning is accomplished by team formation in the lectures and the discussion of design-related issues, hands-on exercises (in-class and laboratory), computer-aided engineering design using the latest electronic simulation and control-design software, and encouragement of critical thinking. Now that the similarities of the two courses taught at RPI have been discussed, a description of the details of each course will be given.

The Mechatronics course is taught in a studio environment with a maximum of 36 students in a section and an average enrollment of 60 students (80% undergraduate). The course is a four hour lecture with a two hour coinciding laboratory. The prerequisites for this course are electronics and instrumentation, dynamic systems, and controls. The labs in this course cover the following topics

- Analog electronics
- Digital electronics, A/D and D/A converters, and microcontrollers
- Stepper motor control
- Thermal system closed loop control
- Pneumatic servomechanism
- DC motor closed loop control

- Magnetic levitation system

The students perform a complete dynamic system analysis for the last five labs. The complete dynamic system analysis requires four steps. First, the students must understand the physical system by developing a prototype to base analysis and design, and experimentally determine/validate model parameters. Second, the students develop a mathematical model of the system, and compare the mathematical model to the experimental results. Third, students design a feedback controller to meet the design specifications. Fourth, the students implement the control system design and validate the controller's performance.

The Mechatronics System Design course is also taught in a studio environment with a maximum of 36 students, with a typical enrollment of 25 to 30 students. This course is also a four hour lecture, with unlimited lab hours for the students to work on projects. The students work in groups of four to complete a project for the end of the semester. Typical projects include the reverse engineering of a successful mechatronics product, and the designing, building, and testing of a project similar in scope to those in the Mechatronics course's labs. For these projects, a written report and an oral presentation is required. Several of the projects completed by the Mechatronics Systems Design class include:

- Ball-on-beam balancing system
- Ball-on-plate balancing system
- Inverted pendulum systems
- Hydraulically-balanced beam system

The control systems for the projects were designed and implemented using the MATLAB/SimuLink/ dSPACE software and hardware. More information on RPI's mechatronics program is provided at http://mechatronics.meche.rpi.edu/ (Craig).

1.3.3 Mechatronics at Georgia Tech

There are three courses taught at Georgia Tech that are considered mechatronics based: (1) Microprocessor Control of Manufacturing Systems (Mechatronics), (2) Digital

Control Systems, and (3) Introduction to Mechatronics. Digital Control Systems and Introduction to Mechatronics are both graduate level courses and will not be discussed here. The overall goal of the Microprocessor Control of Manufacturing Systems is to provide an interdisciplinary, practical, and hands-on approach to mechatronic system design along with the encouragement of teamwork.

The prerequisites for this course are the analog and digital electronics courses and the ME 3056 Lab that includes the Pulse-Width-Modulated (PWM) signal material. The course uses the Motorola HC11 microprocessor. Both the lab and lecture experience are stressed in this course. The emphasis of the lecture is on sensing, controlling, and actuating systems. The material covered in lecture is analog circuit review, digital math, assembly programming techniques, microprocessor structure, and interrupt driven processing. The students in the class present special topics that cover the following topic areas: power electronics, interface electronics, signal processing, A/D conversion, serial/parallel communication, and timers. The ideas stressed within all of the lectures are the theory and application within mechatronics, usable sample code, and proper device sizing.

In the laboratory part of the course, the intended goal is for the student to build devices that can be applied to practical applications. The tools the students should take away from the course are general design techniques, basic circuit construction, and code generation. The lab consists of four projects, a series of informal lectures, and a final group project. The purpose of each lab is to highlight a different skill. The different skills highlighted are soldering, developing assembly code, experimental demonstration, and creating a written report. The informal lectures cover circuit building tips, soldering techniques, basic signal conditioning, EEPROM/EPROM, and modular programming. The final project is required of each student team. Each team defines their project and this project is intended to be achievable. The projects the students do are expected to incorporate a mechanical device, some necessary sensors and actuators, the supporting electronics, and interfacing the HC11. For the final project the students are expected to set their own schedule and then meet weekly with the TA to discuss their progress and

problems. Upon completion of the final projects the students submit written and web based reports along with an oral presentation their project. More information on mechatronics at Georgia Tech can be found at:
http://www.me.gatech.edu/mechatronics_lab/ (Gergh, et al).

1.3.4 Mechatronics at Pennsylvania State University (PSU)

The first course in mechatronics at PSU is called Microcomputer Applications (Mechatronics). This course has been taught at PSU for the past 15 yearsand is aimed at senior mechanical engineering students. More recently there has been a second course added called Mechatronics II. This second course in mechatronics is directed more toward the mechanical engineering graduate students however there is an undergraduate enrollment.

The course description for the Microcomputer Applications includes interfacing electro-mechanical systems to microcomputers for data acquisition, data analysis, and digital control. The course uses the BASIC stamp microprocessor kit that is based around microchip's PIC microcontroller. The course lectures cover the following topics:

- BASIC stamp operation
- PIC microcontroller
- Circuits, transistors, and other analog circuitry
- Digital logic and digital I/O
- A/D and D/A conversion
- Op-Amps and active analog filters
- Sensor/transducers
- Digital filters and Fast Fourier Transform analysis
- Computer architecture
- Data communication
- Electronic packaging
- Digital control

There are seven labs that the students complete throughout the semester. The first lab is to introduce students to the lab and to familiarize them with the BASIC stamp. The next lab also uses the BASIC stamp, but this time it deals with interfacing the PIC processor with other electronics. In the third lab the students create a digital voltmeter using logic chips, A/D, and LED's. The fourth lab covers non-inverting and push/pull power amplifiers. The fifth lab covers stepper motor control. In the sixth lab, students perform motion control, and learn about electrical noise and grounding. In the seventh and final lab analog filters are created. The students analyze their filters using a fast fourier transform of time domain data they collect. The following website is good source of information for this course http://www.me.psu.edu/lamancusa/mechatronics/ME462.htm.

1.4 Mechatronics at Virginia Tech

Mechatronics at Virginia Tech was initiated in 1996. It is a cross-listed course between the Mechanical Engineering (ME) and Electrical and Computer Engineering (ECE) departments. The course is a truly interdisciplinary course, taught by ME and ECE faculty and students of both disciplines enrolled in the course. The course consists of both lecture and lab, with a design project required of all students.

There are several reasons for offering mechatronics at VT. One is to allow students to broaden their knowledge while still taking a course in their major. This greatly reduces the typical problem of students not having the proper prerequisites. Another reason is the increasing importance of interdisciplinary work on senior design projects. Also, internal curriculum review committees, industrial advisory boards, and ABET all recommended stressing interdisciplinary study in the curriculums. The changing nature of products and processes in the past years is another catalyst for the inclusion of a mechatronics course. Increasing use of microcontrollers and electronics in traditionally mechanical products has also led to the need for this type of interdisciplinary course offering.

The general topics covered in the course lecture are shown below:

Dynamic modeling of electromechanical systems	5%
Microcontroller operation, interfacing, and programming	25%
Sensors	15%
Actuators and drive systems	20%
Signal Acquisition and conditioning	15%
Control theory	10%
Programmable logic controllers	5%
Data communications	5%

During the semester the students performed five laboratory assignments, one individually and the rest in teams. All of the laboratory assignments are described on a dedicated website for the students to access. The first laboratory assignment is the individual assembly of the course's prototyping printed circuit board, called the VT84. This board is based on the PIC16F84 (PIC) microcontroller. The main components on the board are the microcontroller, an analog-to-digital converter, an H-bridge, and a DB-9 connector, along with several other chips for serial programming. A more complete discussion of the VT84 and its components is given in Chapter 2. After completing this lab the students form teams of three or four with at least one ECE and a ME. These teams then complete the remaining labs and create a final design project. During the second lab, the students familiarize themselves with the programming environment of MPLAB and the basic operation of the PIC. The focus of the next lab is interfacing the analog-to-digital converter (ADC) with the PIC to echo the binary value to an 8-segment LED array. The fourth lab requires generating a PWM signal to perform open loop-speed control on a DC motor. The final lab assignment brings together all of the previous labs to create a closed loop position control of a DC motor. The semester design projects are conceived by the teams and approved by the instructors. Upon completion of the final projects the groups are required to present and demonstrate them to the class.

As the previous discussions have shown, the material covered in this course and the laboratory assignments are similar to that of the other programs discussed in the previous section. There are two major differences between VT's mechatronics course and the mechatronics courses of other institutions. Mechatronics at Virginia Tech is taught together by mechanical engineering and ECpE faculty. Faculty members instruct in an area that is most related to their background. This gives the student better instruction as well as diverse viewpoints on mechatronics. The other major difference is that the class enrolls ME's and ECpE's and requires students of both disciplines to work together. This interdisciplinary collaboration exposes the students to the type of teamwork required in industry, and allows the students to help one another in an active learning environment.

1.5 Vertical Integration of Mechatronics

In this section an explanation of the vertical integration of mechatronics will be presented along with the tasks that needed to be addressed to accomplish the vertical integration.

In defining vertical integration it is helpful to define the individual words. Then from the combination of the definitions of each word, and using some intuition, a definition of vertical integration will be presented.

Vertical:

Of, relating to, or comprising persons of different status (Merriam-Webster).

Integration:

The act or process or an instance of integrating (Merriam-Webster).

Integrate:

a: to unite with something else b: to incorporate into a larger unit (Merriam-Webster).

In the case of vertical integration, vertical is referring to the students that comprise the different status levels at the university, i.e. freshman, sophomore, junior and senior; and integration is the incorporation of new course material. The vertical integration of mechatronics is the incorporation of particular mechatronics topics into other levels of student population; that is, teaching mechatronics to academic levels preceding either seniors or graduate students.

The first important task was how to incorporate mechatronics in the curriculum. There were two solutions to this problem considered, (1) create a class unto itself that addresses mechatronics at these desired levels, or (2) integrate mechatronics into already existing classes. Due to the experimental nature and the available resources it was decided to integrate mechatronics into preexisting classes. Throughout the duration of the project, mechatronics was integrated into two different courses. The first course was Mechanical Engineering Design (ME 2024) and the second was System Dynamics (ME 3514).

1.6 An Overview of the Vertical Integration of Mechatronics at VT

There were several strategies used to facilitate the integration of mechatronics. One of the strategies was to make the application of microcontrollers easy for the students. Another strategy was to provide demonstrations of mechatronics concepts and products. Another strategy was for the students to obtain a hands-on type experience.

In order to accomplish the integration it was necessary to create tools for the students to use that would make it possible for them to obtain a level of understanding of mechatronics. The tools created were the VT Project box and PIC Visual Development (PVD) software. A picture of the project box is shown in Figure 1.1 and an example of a PVD program is shown in Figure 1.2. The VT Project Box is built around the VT84 board used in mechatronics, ME 4734. The PVD software is a block diagram programming environment that was created for use with the VT84. A detailed presentation of the project box and the PVD software will be given in Chapter 2.

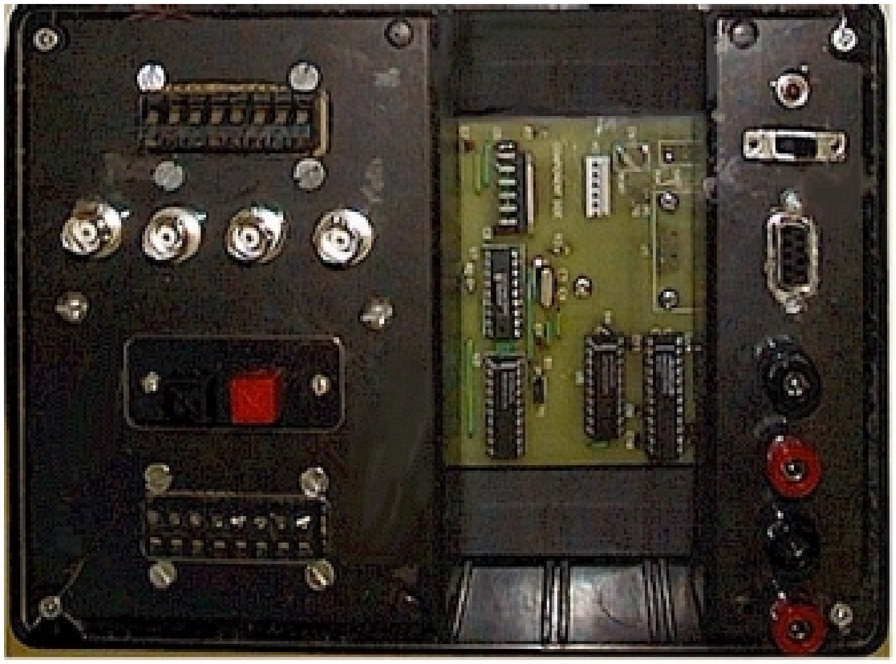

Figure 1.1: The Virginia Tech Project Box

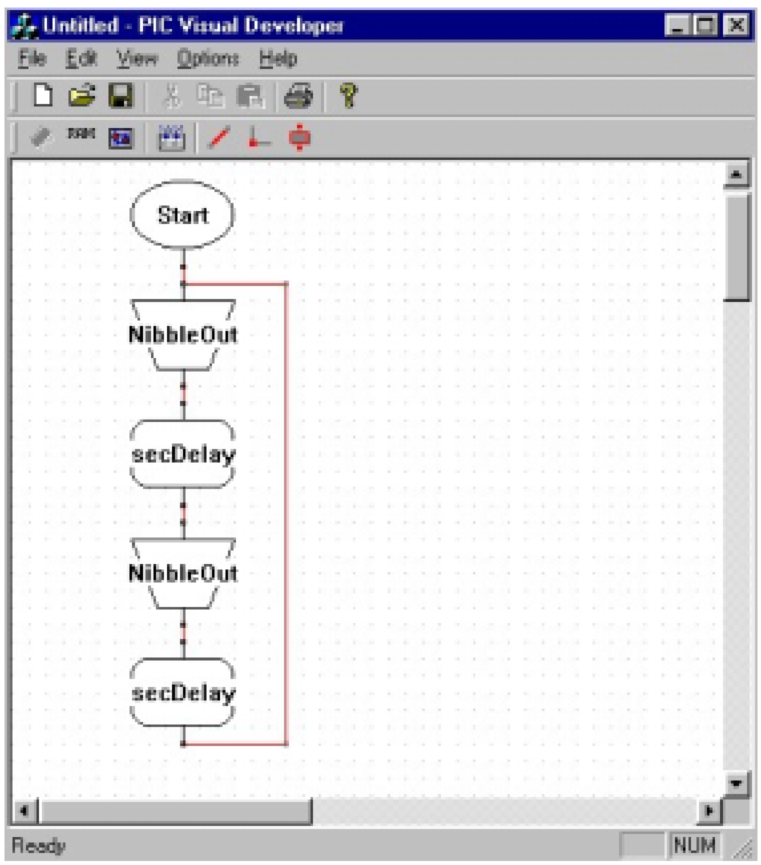

Figure 1.2: An Example PVD program.

The first experiment was the creation of an optional project for a sophomore level course in which the students would have exposure to various aspects of mechatronics. The tools used were the VT Project Box, PVD Software, and various sensors and actuators. These tools were used in two ways: (1) as a demonstration aid to show some simple applications of mechatronics and (2) for the students to use to prototype their final design projects in the class. As a result, an entire section of the sophomore class was exposed to mechatronic design, and the students who chose to do so worked with the research assistant (RA) to create a prototype of their final project, which involved some aspect of mechatronics.

The second experiment was a required design project in a junior-level system dynamics course. In the design project the students were required to create a program using the PVD software. The program would perform open-loop speed control of a DC permanent magnet motor. After the program was created and downloaded to the project box the students ran the program and collected steady-state speed data from the motor's integral tachometer. Next, the students created a linear model of the system and compared the steady-state response of the model to that of the actual system.

1.7 Summary of Results of the Vertical Integration of Mechatronics

At the end of the semesters, a questionnaire was given to the students in both courses. The surveys asked basic questions to see how the inclusion of mechatronics was perceived, and whether it should be included in future offerings of that course. The questions and results are presented in Chapters three and four. The following is a brief synopsis of the results.

The overall goal of incorporating mechatronics into the sophomore design course was to show the students in the participating sections how mechatronics is a design philosophy and to increase the students' interest in mechatronics. In the sophomore course, there were nine students who participated in the optional mechatronics project. Because the number of students who participated was small a written-response survey was given. The results of the survey indicated that the students thought the incorporation of mechatronics was a good idea for the course. However, students felt there needed to be more time to complete the final project if mechatronics was to be involved. The timing of the final project was not ideal. There were only three weeks for the students to prototype an entire mechatronics project. This time constraint not only made it difficult for the students to complete the projects, but also made it difficult for an RA to help the students complete the projects in the allotted amount of time.

The goal of integrating mechatronics into the system dynamics course was to increase the students understanding of the course material and give the students exposure to mechatronics. The implementation in the junior course was different in its application. Instead of being optional, it was required as part of a design project incorporating mechatronics. Since it was mandatory, all of the students were surveyed using an op-scan format (see Appendix III.A.a). The result of the surveys showed that there was an increase in the students' understanding of the course material, and an increased interest in mechatronics, in general, from the lab experiment they completed.

1.8 Dissemination of the Vertical Integration of Mechatronics Material

A key purpose of the NSF/SUCCEED coalition was the dissemination of course material developed under its funding. The appendices of this thesis include the necessary supporting material for dissemination to other institutes. In Appendix I, the necessary information for constructing a VT Project box is included. This appendix outlines all of the parts that need to be purchased, all of the schematics necessary for construction, and step-by-step instructions for the creation of a VT Project Box. Appendix II is a user's manual for the PIC Visual Developer, this appendix outlines the various functions of the PVD software, and gives a step-by-step example of creating a program using the PVD software. Appendix III contains the material created for the ME 3514 course: a PowerPoint lecture, a lab manual for the course, the design project assignment, the survey, and the survey's raw data. The lab manual for the course gives step-by-step instructions on how to create a PVD program and how to use the VT project box. The PowerPoint lecture contained in this appendix provides a good introduction to mechatronics and details about the design project assignment in ME 3514. Also, the survey given in this course and the raw data obtained from the survey can be found in this appendix. One main objective of this work was to allow other institutions to use the material developed at Virginia Tech to integrate mechatronics into their curriculum.

1.9 Presentation of Thesis

After this introductory chapter, the various tasks associated with the vertical integration of mechatronics are discussed in Chapter 2. Chapter 2 details the selection of appropriate courses for the vertical integration of mechatronics, and discusses the hardware and software created for the vertical integration.

Chapter 3 discusses the objective's of ME 2024, and the layout of the course. It then proceeds to detail the vertical integration of mechatronics into the course, which was achieved by allowing the students to incorporate mechatronics into their design projects. At the end of the semester, the students prototype their final projects. At the end of the semester a survey was given to all students who participated in a mechatronics project. The results of this survey are also presented in Chapter 3.

The objectives and the layout of ME 3514 are discussed in Chapter 4. The details of the vertical integration of mechatronics into this course are presented next in the chapter. Mechatronics was integrated into this course by incorporating it into a design project required by all students to complete. The students of this class were also surveyed, and the results of the surveys are presented.

In Chapter 5, a general summary of the vertical integration of mechatronics is presented. A brief synopsis of the results of the vertical integration of mechatronics into ME 3514 and ME 2024 is given. The author's view of an ideal vertical integration of mechatronics is detailed.

Chapter 2

The Task of Vertically Integrating Mechatronics

Four techniques were considered regarding how to vertically integrate mechatronics into other levels of the mechanical engineering curriculum. One idea was to create an entire lecture course at the sophomore or junior level. The second idea was to create a one-credit hour lab course. There was also a concept to create a combination of these into a lecture/lab course. The final possible way to integrate mechatronics would be to include it as a part of an existing course, e.g. one lab in a course, part of a design project, several lectures in a course, etc. The first three possibilities were the most direct way to vertically integrate mechatronics, but they were also the most intensive as far as development, finances, and being accepted into the curriculum. The final possibility still required intense development, but the cost of this development would be much less and this method could readily be integrated into current courses. It was through this thought process that it was decided to incorporate mechatronics into a preexisting course.

2.1 Tasks

In order to vertically integrate mechatronics there were several tasks that needed to be addressed. The first task was to decide how to make the senior-level material of mechatronics understandable to sophomores or juniors. The next task was to determine the appropriate course, or courses, in which this material should be included. The final task would be how to implement the vertical integration into the selected courses. These tasks could not be carried out entirely sequentially, it was necessary for them to occur simultaneously. The following sections detail the execution of these tasks, some of the problems encountered, and the resulting courseware.

2.1.1 Defining Mechatronics Content for Sophomore and Junior Courses

There were several considerations that needed to be addressed in the process of vertically integrating mechatronics. One important consideration was that numerous mechatronic design principles needed to be narrowed down to a few lectures and perhaps a single laboratory experience. The prerequisites for mechatronics are another consideration. Due to the nature of the mechatronics course the mechanical engineering seniors are required to have taken ME 3514, System Dynamics. The scope of the material to be introduced was further limited since, the sophomores and juniors did not have these prerequisites. Because of these considerations, communicating the essentials of mechatronics was imperative to ensure successful integration into the desired course. The resulting tasks were to decide what essentials of mechatronics needed to be communicated to the students and how to communicate them.

The essential elements of mechatronics were not straightforward to determine. The students in VT's mechatronics course have often noted that the lab portion of the class was essential to demonstrate mechatronics. Therefore, it was decided that the integration should include a lab exercise that the students could use to obtain hands-on experience. In the lecture part of the course, a decision was made to talk about the basic concepts of mechatronics. This was accomplished by giving a brief definition of mechatronics, several examples of mechatronic products, and emphasizing mechatronics as a design philosophy. The next decision was how to create a laboratory experience that would be beneficial to the host course and would provide motivation for individual students. This could not be determined until an appropriate host course was selected. It was determined that there were two elements that would be necessary to make the laboratory experience involve mechatronics. One such element was interfacing a microcontroller to other electronics or to a mechanical system. The other would be actually programming the microcontroller. Interfacing was accomplished by creating a "black box", so all the students needed to do was know how to program the chip, power up the box, and what inputs and outputs needed to be connected. Programming the microcontroller was handled in a similar manner. A programming environment was created to allow the students to program the microprocessor in a block diagram format. The "black box", subsequently named the VT Project Box, and the software, referred to as the PIC Visual Developer (PVD), will be discussed in greater detail in later sections of this chapter.

2.1.2 Determination of Appropriate Course

In vertically integrating mechatronics it was important not to detract from the host course's material. It was also necessary to make sure the topic of mechatronics fit into the framework of the class, or make it so that the mechatronics exercise complemented the course work. With this in mind several courses were examined for an appropriate fit. The two courses that seemed to best accommodate a vertical integration of mechatronics were Introduction to Engineering Design and Economics (ME 2024) and System Dynamics (ME 3514). ME 2024 was the first choice of a course to integrate mechatronics and ME 3514 was the second. ME 2024 was the first choice because it was a class concerned with design philosophies. ME 2024 was an ideal place for mechatronics since mechatronics is a design philosophy. ME 3514 was chose because its topics are concerned with the interconnections of systems. ME 3514 was a good place for the integration of mechatronics as well, because mechatronics can be thought of as an interconnection of mechanical and electrical systems.

ME 2024 was selected as a course to integrate mechatronics because, it was a course focused on developing engineering design skills. This course provided a possible integration at the basic design level, before students would learn about the complex physical limitations imposed by most mechanical engineering systems. The format of the course would also allow the students to prototype their final design projects. This would provide students with the desired hands-on experience with mechatronics hardware as well as a subset of the basic principles behind mechatronic design. Recall that these were the two main goals of the integration project. Further discussion of the ME 2024 will be provided in Chapter 3.

The ME 3514 (System Dynamics) course was a suitable place to integrate mechatronics, as well. This course focused on mathematically modeling dynamic systems. The systems modeled include mechanical, electrical, thermal, fluid, and combinations of these systems. This was an ideal situation for discussion of mechatronics concepts because of the electro-mechanical system analysis and signal analysis that was completed by the students. Mechatronics was integrated by incorporating a mechatronics lab exercise as part of a design project. The students were required to participate in the lab. There were two lectures presented to the class explaining mechatronics and the purpose of the lab. More information on this course and the vertical integration of mechatronics in this course will be provided in Chapter 4.

2.1.3 Metrics of Success

Two metrics, the students' response to surveys and the objective perception of the instructor/RA, were used to measured the success of the vertical integration of mechatronics. The students in the two courses were surveyed differently because of the difference in the number of students who participated. In ME 2024 the distributed surveys asked three specific questions to which the students gave written responses. This was an ideal way to collect the students' thoughts on the vertical integration since, there were a small number of students who included mechatronics in their final project. In the systems dynamics course all of the students were required to participate in the mechatronics design project. Therefore, individual surveys with written responses would have been difficult to process. With that in mind an op-scan survey was created for the students. A copy of this survey can be found in Appendix III. The results of the ME 2024 surveys will be presented in Chapter 3 and the results of the ME 3514 will be presented in Chapter 4. The perception of the instructor/RA, was performed the same for both courses. The perception of the instructor/RA entailed an objective assessment of the students and the benefits of the incorporation of mechatronics.

2.2 Hardware

Both of the courses required the students to use hardware related to mechatronics. The ME 2024 course needed hardware for the students to prototype their final projects. The ME 3514 course needed the hardware to demonstrate mechatronics to the students. The hardware designed and constructed for the vertical integration of mechatronics needed to be complex enough to demonstrate the concepts of mechatronics, yet simple enough that the students could use it in their lab exercise.

2.2.1 Requirements

A key objective was to ensure that a second-year student could use a microprocessor and its accompanying integrated circuits. This was accomplished through the creation of a project box and a block-diagram programming environment. The creation of the block diagram programming environment will be presented in a later section of this chapter. The project box needed to accommodate multiple signal types: analog input/outputs and digital inputs/outputs. The decision was made to build the project box using the VT84 board, Figure 2.1. The VT84 board is built by each of the students in the fourth-year mechatronics course. A VT84 board was used in the project box for several reasons. One reason use was the familiarity the author has with the board. Another reason for the use of the VT84 was that all of the components were readily available, and a final reason for using the VT84 was that a new prototyping board design did not have to be made for the course.

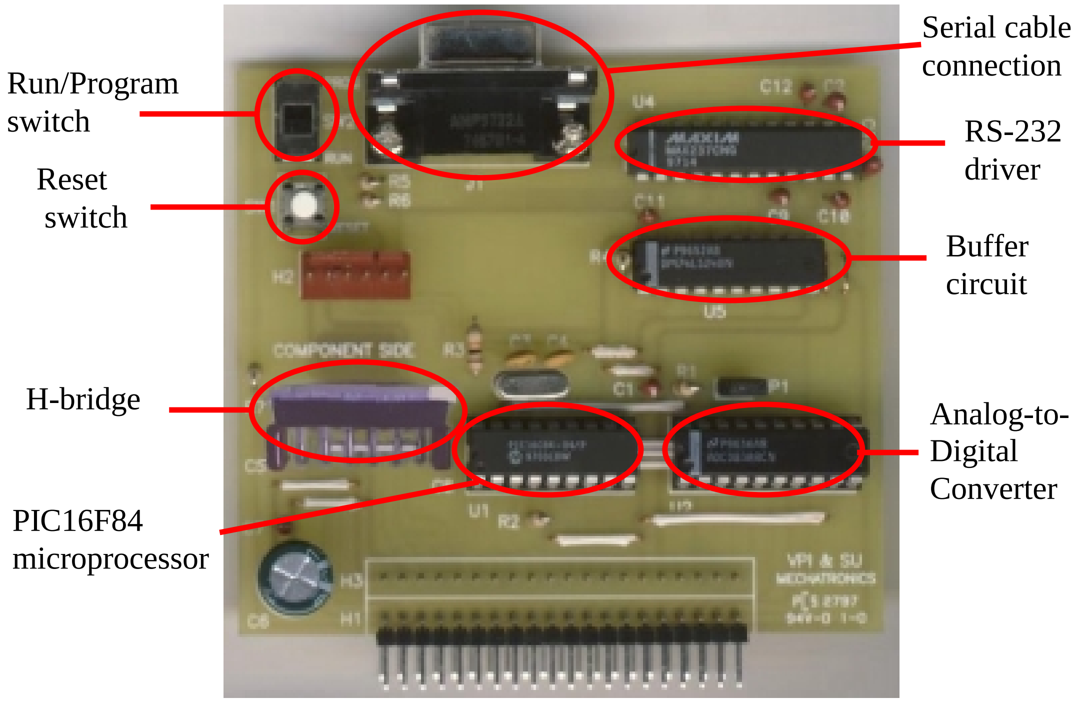

Figure 2.1: The VT84, the VT mechatronics prototyping board

After choosing the VT84, determining the inputs and outputs for the box became the next issue. In order to give an amount of flexibility with the box it was decided to use four of the eight analog-to-digital converter (ADC) channels as analog inputs and four of the eight PIC digital channels as digital inputs. The H-bridge was included as an output, since it was the only power-providing IC. The other four digital channels were used as digital outputs. The VT84 imposed the remaining requirements. These requirements were a 5-volt input, a 12-volt input, a DB-9 connection, a SPST momentary switch, and a DPDT switch. The 5-volt input powered the PIC and the ADC when the DPDT switch was in the RUN position. The 12-volt input powered the PIC when the DPDT switch was in the PROG position and powered the H-bridge when the switch was in the RUN position. The DB-9 connection was for programming the PIC from a PC. Programming could be done when the DPDT switch was in the PROG position. The momentary switch was used to reset the processor before programming, and it was also used to reset the program to the beginning of the program when the DPDT switch is in the RUN position.

2.2.2 A brief description of the VT84's Integrated Circuits (IC's)

The reason for describing the VT84 is to familiarize the reader with the capabilites of the prototyping board. The relevant IC's on the VT84 included the PIC16F84 microprocessor (PIC), an 8 channel analog-to-digital converter (ADC), and an H-Bridge. The PIC has thirteen configurable digital channels. It requires a 12-volt input to be programmed and a 5-volt input to execute the program. The PIC has a total of 32 instructions. On theVT84 board the processor operates at one instruction per microsecond. There are two modes in which the PIC operates, run mode and program mode. By applying 12-volts to the program voltage pin, the PIC is put in program mode. The PIC can then be programmed on the VT84 board using a serial connection from a PC. There are two IC's on the VT84 that receive the data from the serial connection and communicate it to the PIC for programming. One of the chips is a buffer chip and the other is a MAX237 chip, a RS-232 driver/receiver chip. Two of the PIC's digital pins are used during programming. After programming, the PIC is put in run mode by removing the 12-volts from the program voltage pin and applying 5-volts to the power pin. The switching of the appropriate voltages to the appropriate pins is handled on the VT84 board by the DPDT switch. Placing the switch in the RUN position puts the PIC in run mode, and sliding the switch to the PROG position puts the PIC in program mode. These positions are marked on the VT84. On the VT84 five of the thirteen digital channels are used to communicate with the H-bridge and the ADC, while the other eight are free to be used as necessary by the programmer. The ADC has eight channels and has an eight-bit resolution, the volts/bit depend on the reference voltage. On the VT84 the ADC has a reference voltage of 5-volts, this results in a resolution of 19.5mV/bit. Three of the pins on the ADC are used to communicate with the PIC, one pin is for timing, another is for turning on the ADC, and the third is for setting up the ADC and transmitting the digital value of the analog signal. The H-bridge is built around four power-switching transistors. H-bridges are often used to control the position, speed, or torque of DC and stepper motors. On the VT84 the H-bridge is powered by 12-volts. The H-bridge creates an output signal based on the input to the PWM and direction pins. Two pins on the PIC controls the PWM and direction pins on the H-bridge. For datasheets and further information on the VT84 one can go to:
www.mechatronics.me.vt.edu.

2.2.3 Design of the VT Project Box

The first task was to create a prototype demonstrating the packaging of the VT84 board into a project box. A picture of the prototype can be seen in Figure 2.2. In the proof of concept a 15-pin connector was used to read the outputs of the 13 digital channels of the PIC, 2 ADC channels were connected to BNC's, and connections to the H-bridge were connected to a speaker jack. The first prototype was made in a 3" by 5" project box from Radio Shack. After the construction of the proof-of-concept box several changes were made to the design. The first change was the separation of the digital inputs and outputs. Also, the connectors for the digital inputs and outputs were changed from the 15-pin connector to screw terminals with a ground for each channel. Another change was moving to a larger box. There were two reasons the box size was increased: (1) to separate the inputs, outputs and power/programming connections, (2) to allow for a plexi-glass cover to make the VT84 visible to the user. Two sub-assemblies were created when the box size was increased. One sub-assembly contained the digital I/O, the ADC connections and the H-bridge output; a picture of this sub-assembly can be seen in Figure 2.3. The other sub-assembly supported the DB-9 connection the 12-volt input, the 5-volt input, the reset switch, and the mode selection switch; a picture of this sub assembly can be seen in Figure 2.4. In the design of the second prototype these sub-assemblies were made of the 3" by 5" box, this is shown in Figure 2.5. After the first box was made a third box was made using a sheet of plastic for the sub-assemblies instead of the smaller project boxes, Figure 2.6. A construction manual and schematics for the project box are in Appendix I. Another improvement in the final design of the project box was the change to 1/8" plexi-glass from 1/4" plexi-glass; this change allowed the deletion of spacers under the BNC connectors of the ADC. The final design of the project box can be seen in Figure 2.7.

Figure 2.2: Original prototype of the VT Project Box

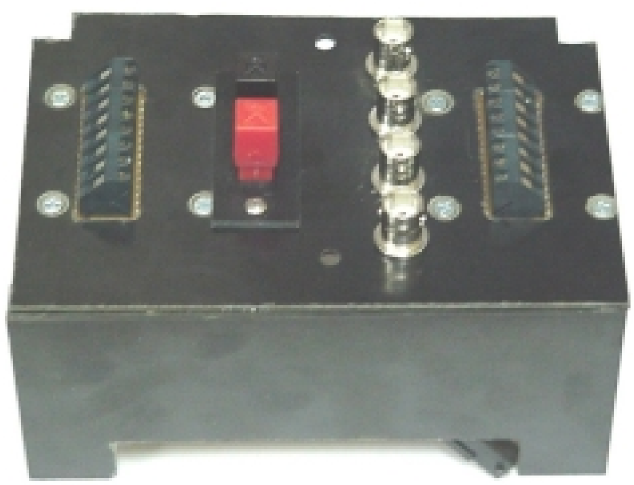

Figure 2.3: Large Sub-cover for the VT Project Box

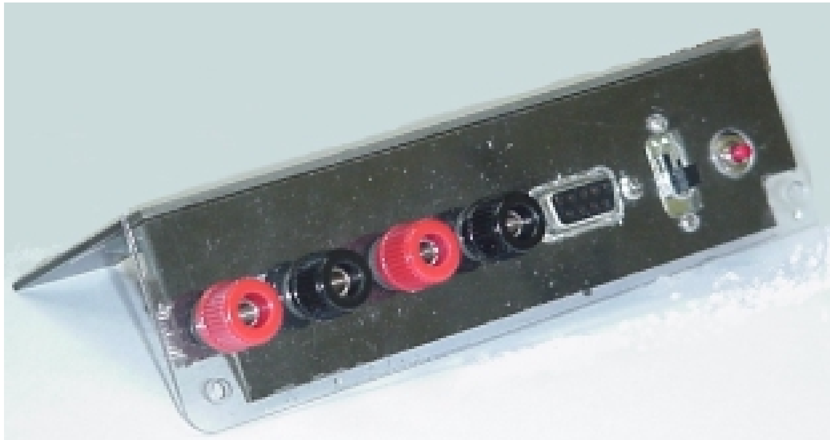

Figure 2.4: Small Sub-cover for the VT Project Box

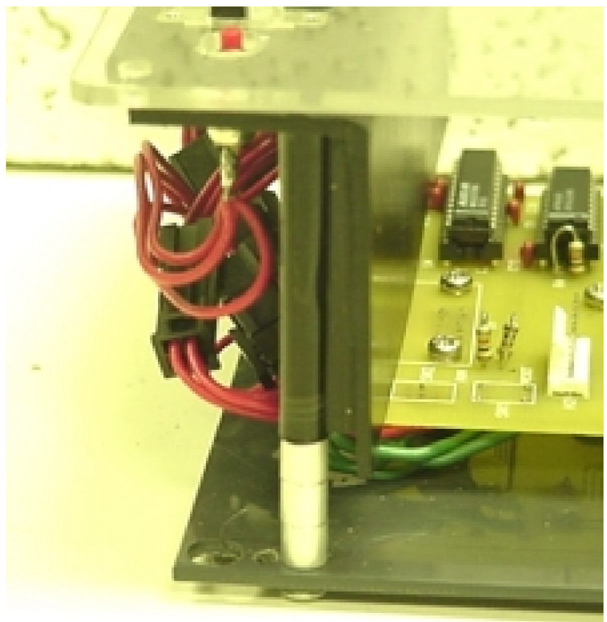

Figure 2.5: Project box sub-assembly made of 3” by 5” project box

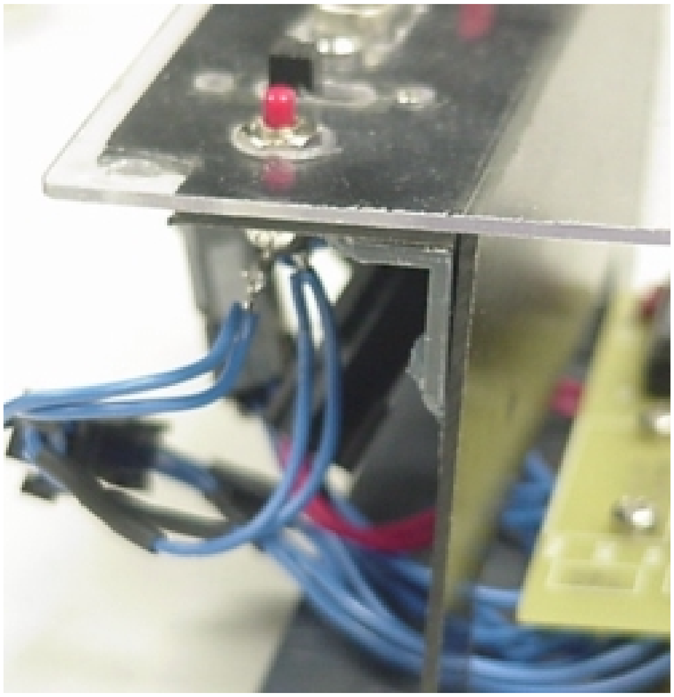

Figure 2.6: Improved Project box sub-assembly

Figure 2.7: Final Design of project box

2.3 Software

For the vertical integration to be successful not only did a project box for the students need to be constructed but also software they could use to program project need to be developed.

2.3.1 Requirements

Making the IC's of the VT84 work in concert with the microprocessor was relatively complicated. The creation of a programming environment usable by a second-year student was a necessity. The software that created was named the PIC Visual Development (PVD) software. The C++ programming environment was characterized by the visual interconnection of blocks that define various operations for the Project Box to perform. Each block had specific parameters associated with it that determined how its operation was carried out (e.g. which variables to add). After creating the block diagram program, the software took the code, converted it to assembly language, and compiled it for downloading to the PIC. The types of blocks used for programming included single-ended reads ADC, differential-ended reads ADC, 4-bit digital input, 4-bit digital output, 4-bit AND, millisecond delay, one-second delay, add, subtract, multiply, and several others. With this combination of commands many useful programs could be written for the PIC.

2.3.2 Usage

Creating a PVD program consisted of several steps. The first step was to place blocks in the programming environment. The next step was to define the blocks. In defining the blocks one chose the block type, e.g. an add block. Also in defining the block it was necessary to define the inputs and outputs, for example, with the add block the variables or numbers being added would be the inputs and their sum the output. After the blocks were defined in this manner, they were connected together in the order of execution. The program was compiled by PVD and a .hex file was created. The .hex file could be downloaded to the project box to execute the program. An instruction book for the PVD software can be found in Appendix II, and a detailed example of creating a program can be found in the ME 3514 lab manual in Appendix III C.

2.3.3 Applications

In this section two examples of programs made with PVD are given and explained in some detail.

The first program presented is the program created by the sophomores to familiarize them with the software. Figure 2.8 is a screenshot of the final program. The start block is required for all programs. The next block, NibbleOut, sends a 4-bit value to the output pins (one bit for each pin) of the project box. In this program the value for the first NibbleOut is 1111 binary, 15 decimal. The secDelay, is a one second delay. The next NibbleOut sends 0000 to the output. Then there is another secDelay and the program returns to the first NibbleOut. The effect of the program is to turn on all of the outputs for one second, then turn them off for one second. With a LED array attached to the output, the LED's flash on for one second then remain off for one second.

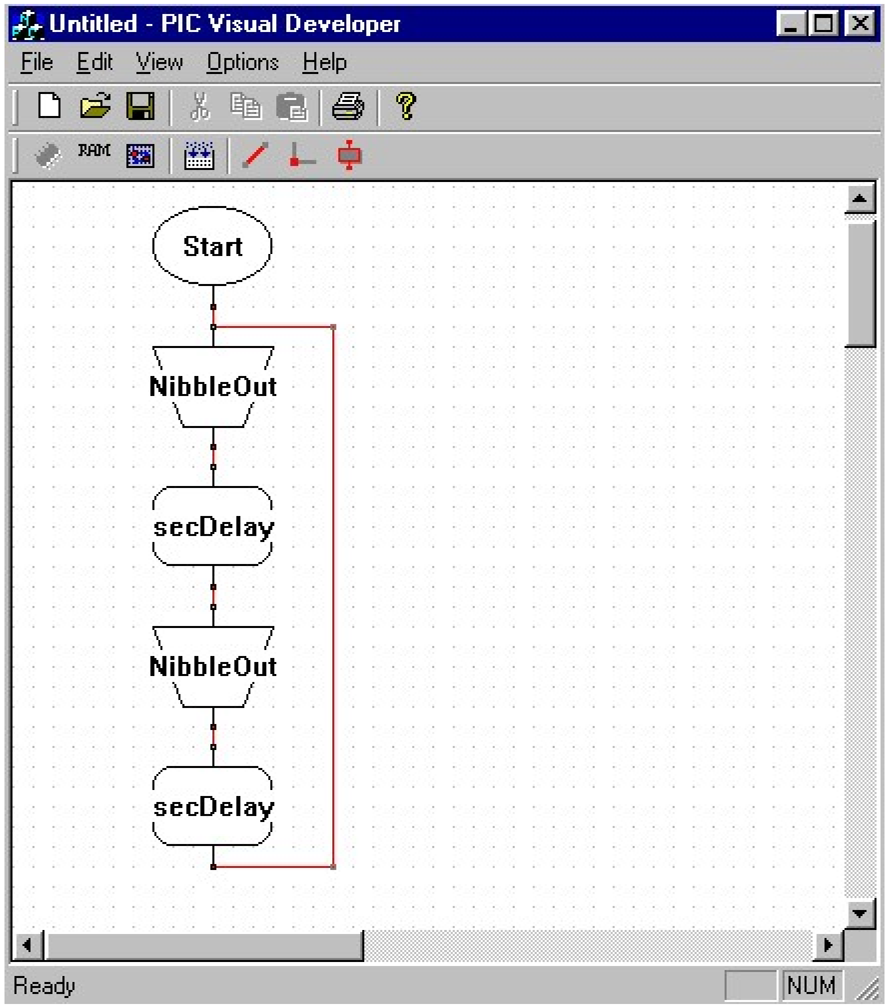

Figure 2.8: Example PVD program used by the ME 2024 students

The next program shown is the program created in the ME 3514 course for the laboratory assignment. This program is for the open-loop speed control of a DC motor. The PVD program can be seen in Figure 2.9. The first block in this program is again the start block. The next block is a Pot1 block; this block creates the code to perform a single-ended read from channel one of the ADC. After reading channel one of the ADC, the 8-bit value (0-255) is stored in a variable defined by the programmer. The subtract-block subtracts 10000000 (128) from the value input to the Pot1 block. There are two outputs from the subtract-block, sign and magnitude; the programmer assigns these outputs variable names. The Multiply block multiplies the magnitude result of the Subtract block by two. The SetSpeed block determines the percent duty cycle output by the H-bridge. The range of input to the SetSpeed block is from 0-255. The input to the

SetSpeed block is the result of multiplication block. The maximum number resulting from the subtraction can only be 127; therefore, multiplying by two gives a range of 0-254, nearly the range of the SetSpeed block. The SetDirection block then determines the polarity of the PWM signal of the SetSpeed block. The input to the set direction can have two values 0, or 1. The input for this block is the variable for the sign of the subtraction; which has a value of 0 or 1.

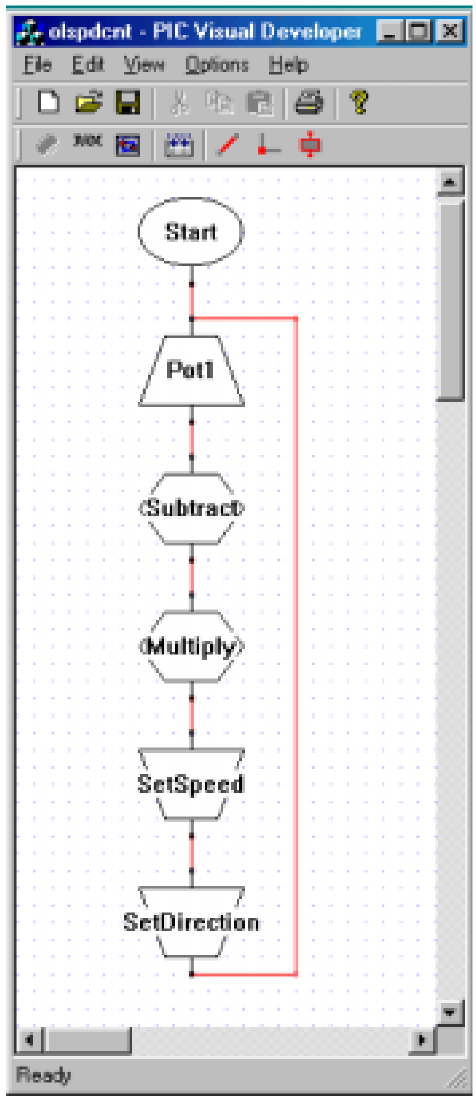

Figure 2.9: PVD open-loop speed control program used in the ME 3514 design project

Chapter 3

The Vertical Integration of Mechatronics in ME 2024 – Introduction to Engineering Design and Economics

This chapter is concerned with the vertical integration of mechatronics in ME 2024. The first section discusses the layout and objectives of this course. Understanding the nature of the course that mechatronics is being integrated into is important; because, without understanding the course, integrating mechatronics correctly becomes difficult. After the discussion of the course, the implementation of the vertical integration of mechatronics will be discussed. This section will detail the incorporation of mechatronics, the demonstrations and examples presented , and the projects that resulted from the vertical integration of mechatronics. The final two sections of this chapter detail the results of the survey and the assessment of the success of the vertical integration of mechatronics.

3.1 ME 2024 – Introduction to Engineering Design and Economics

The description found in the course catalog for ME 2024 is

> Design process, mini-design projects, collaborative design, product dissection, economics of decision making, reverse engineering, intellectual property, oral, written, and graphic communications, engineering ethics.

3.1.1 Course Philosophy (Course Proposal and Course Policy)

The course was introduced into the mechanical engineering curriculum to teach students basic topics essential for engineering. These topics included the design process, ethics, intellectual property, oral presentations and record keeping (logbooks). Another reason for this course was to teach the design process in a way that is encountered in industry. The way the design process usually occurs in industry is in teams, and in industry the problems usually do not have only one solution. So the teaching method of the course was to require teamwork on all assignments and many of the problems had open-ended solutions. This course was an introductory course in design where the students would learn the basics of design and be able to apply these basics in future design courses. A final reason for this course was to enforce the idea of cost effective design solutions.

There were several learning objectives for this course. One objective was for the students to learn how to define problems and find reasonable solutions. Another learning objective was for the students to become acquainted with design report creation and presentation, both oral and written. Finding cost effective solutions using different economic measures was another key learning objective for the course. The learning of engineering principles was taught through reverse engineering products and determining what principles were used in the design of the product. Another learning objective was for the students to be able to complete patent searches to establish state-of-the-art technology. The students were also to learn how to keep logbooks of their activity, so to keep a record of their work and any patentable ideas. The students were to understand the engineering code of ethics and how it is used in decision making.

The material covered in this course follows:

Defining the problem (identifying customer needs, multiplicity of correct answers to problems)	6%
Program plan (tasks, resources, time)	3%
Ideation techniques (brainstorming, inversion, morphological charts, etc.)	6%
Visual representation (sketch exercises)	6%
Reverse engineering(how, why did they do that?)	6%
Identifying ideas which are solutions to the problem (which ideas satisfy the defined problem?)	3%
Intellectual property (patents: to protect your invention, to learn state of the art, and to identify those patents which duplicate your ideas, logbooks for record keeping)	6%
Criteria (weighting used to select best solution)	3%
Analysis of solutions	6%
Estimating the cost of solutions, engineering economics	19%
Decision making using criteria, decision matrices (ownership of solutions, unbiased evaluation of solutions)	6%
Detail design (specify geometry, materials, manufacturing techniques, design for assembly, service, or recycling)	9%
Written communication of design (CAD drawings, illustrations for reports, and memos)	9%
Oral communications of designs (presentation to sell an idea)	6%
Engineering ethics case studies	3%
Engineering teams (dynamics of teams, conflict resolution)	3%

One key element of ME 2024 was the team learning. For the team learning the class was divided into teams of three, and if necessary a team of four or a team of two was created. These teams worked on all assignments together and submitted one solution for each assignment. The team would receive the same grade for each of the assignments. The only assignments the students did not receive the same grade on were tests and design projects. The students took the tests individually and the tests were graded individually. The students worked on the design projects as a team, but upon submitting for grading a form was included accounting the work of each student on the team. When grading the design projects the students were graded on what they individually accomplished and what the team accomplished.

3.2 Implementing The Vertical Integration

3.2.1 Incorporating Mechatronics

The mechatronics material was incorporated as part of the class lecture as well as various demonstrations of mechatronics were presented in the classroom. The class periods were used mostly to prepare the students for five group-design projects the students were required to complete. The fifth project requires the student groups to make a final product design based on the two previous design projects. At this point the groups are encouraged to create a prototype of the product for a final presentation. The groups that had mechatronics oriented projects can approach the research assistant (RA) and request help with a mechatronic prototype. At this point the RA assists the students in determining the level of detail required for the prototype to demonstrate the product concept. Then, along with the RA the necessary sensors and actuators are specified and purchased. Afterwards, the students are required create a sample program for the Project Box using the PVD software. Next, the groups use the PVD software to create a program for the project box that will control the actuators and sensors in their prototype. After the development of the program the groups begin construction of the physical prototype. Upon completion of the physical prototype the project box is connected to it and the entire prototype is then tested and troubleshot along with the assistance of the RA. Upon completion of the entire process the project is presented to the class and the prototype is used to demonstrate the product concept. The procedure used in the class is demonstrated in Figure 3.1.

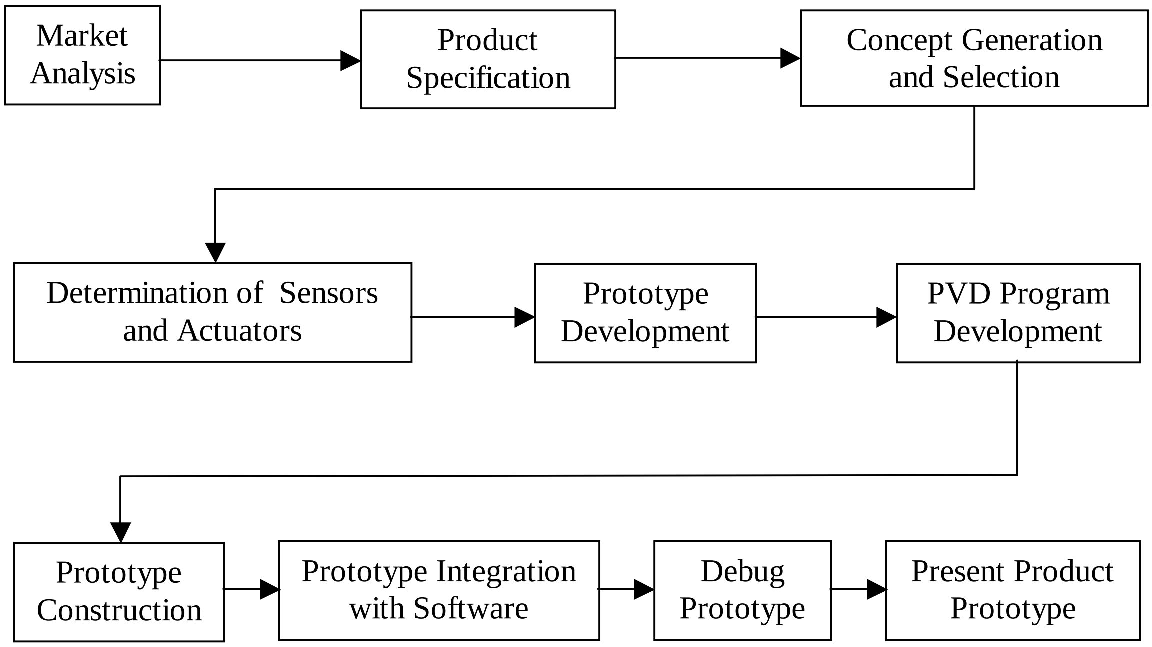

Figure 3.1: Mechatronics Design procedure used in ME 2024.

3.2.2 Demonstrations and Examples

There were several sensors and actuators purchased for the students to see as examples. The sensors available for use included potentiometers, temperature-sensing IC's, accelerometers, microphones, thermistors and a frequency to voltage converter. The actuators used for demonstrations and projects included motors, fans, piezoelectric buzzers, light bulbs, LED's, solenoids, and speakers. During the semester two examples of mechatronic devices were demonstrated and the students created one sample program. The first in-class demonstration was the position control of a link. The PVD code written for this application is shown in Figure 4. The link was mounted to a motor on a stand that used a potentiometer to sense position. Another potentiometer supplied the reference position to be achieved. With this example, the ease of programming the PIC with the PVD software was demonstrated along with some of the capabilities of the Project Box. The aspects of the software demonstrated were the ease of creation and the simple components needed to make such a block diagram. The Project Box's capabilities demonstrated were single-ended reads and the actuation of the motor.

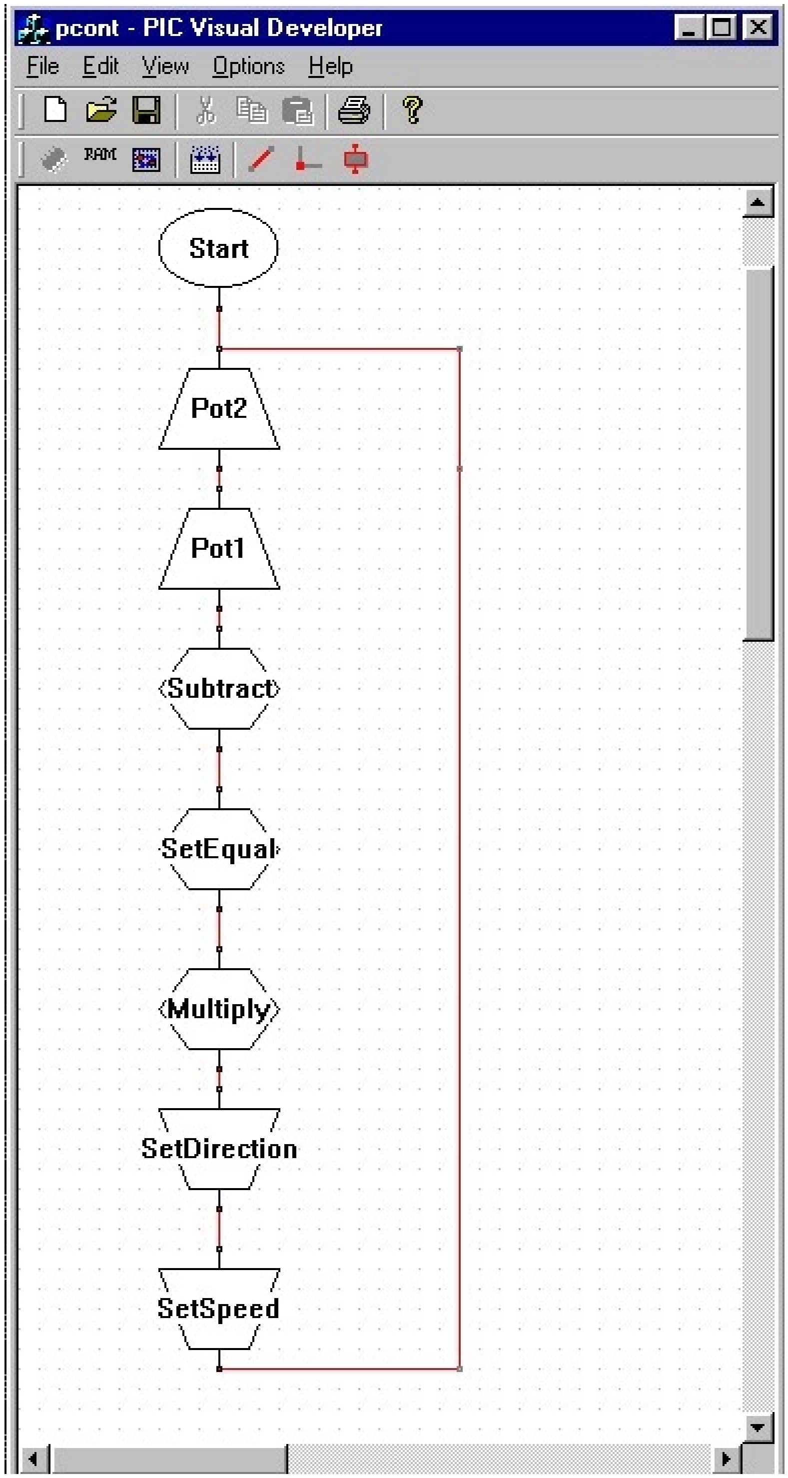

Figure 3.2: PVD program for closed loop position control of slewing beam.

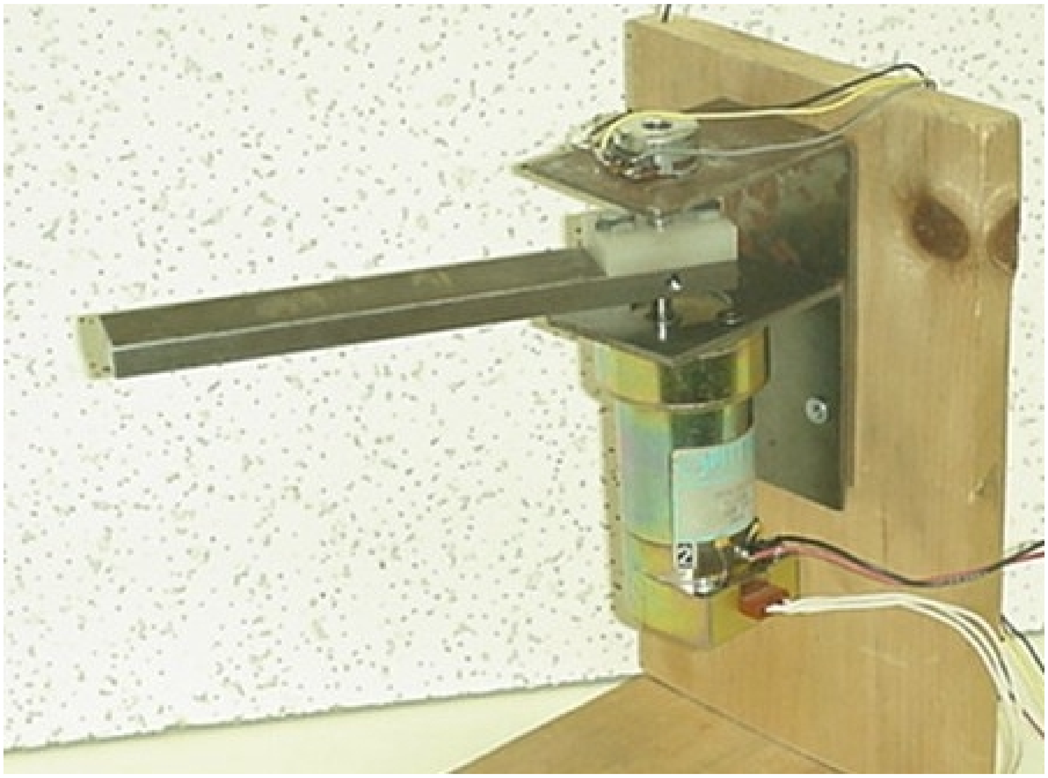

Figure 3.3: Slewing beam arrangement.

The second in-class demonstration given was the temperature control of an IC by a fan. The IC being cooled was a temperature sensor. The premise of this example was when the IC heated up beyond a certain temperature a fan would activate to cool the IC. The fan speed was proportional to the temperature difference between the desired temperature and the actual temperature of the IC. The PVD block diagram program is shown in Figure 5. The code for the temperature control was, in general, similar to that for the position control, but this demonstration exposed the students to another sensor (the temperature sensing IC) and another actuator (the fan).

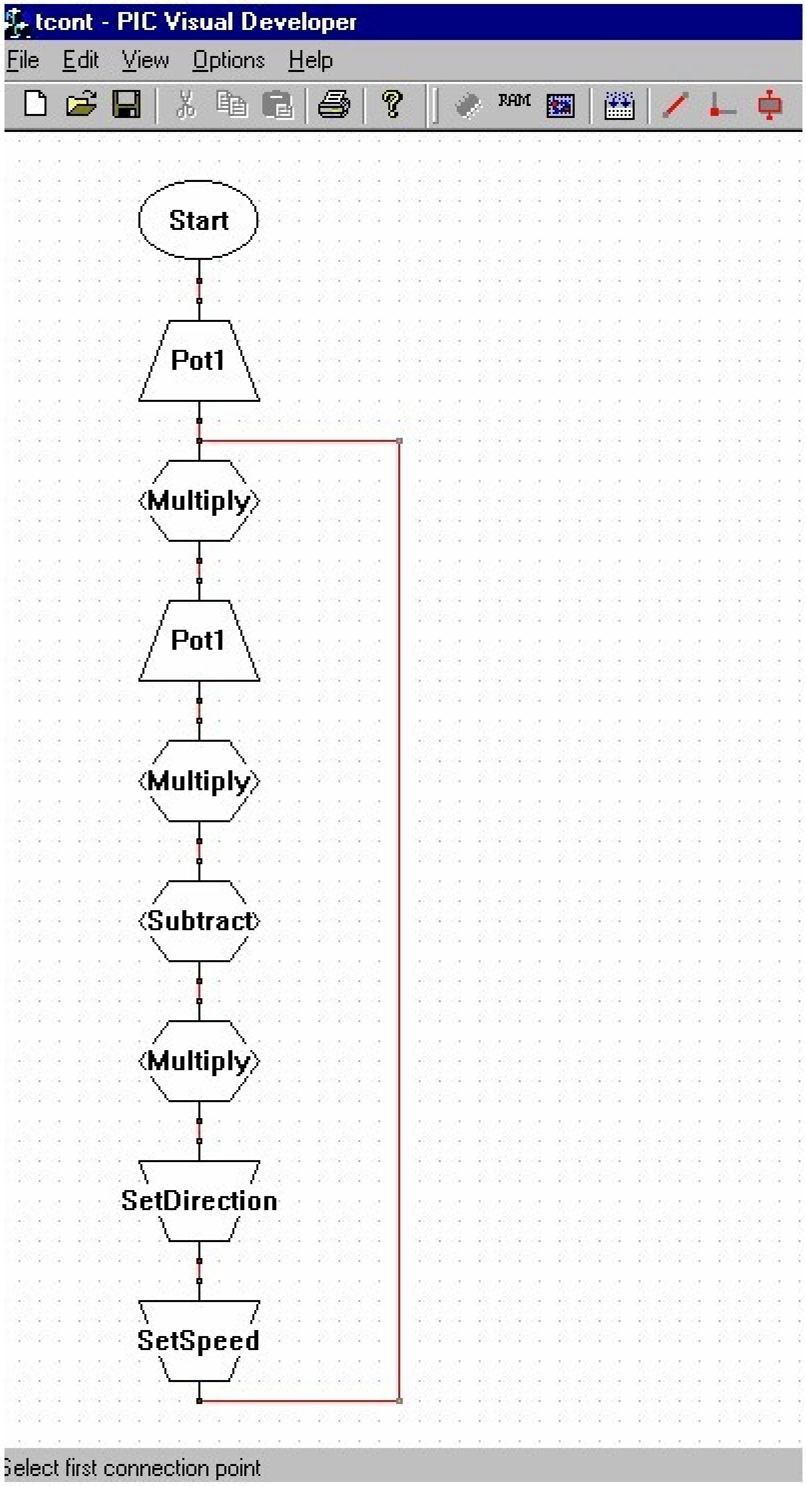

Figure 3.4: Temperature control program created in the PVD environment

After showing students these two examples, those students who planned to do a mechatronics prototype created their own sample program. The sample program that the students created was a simple program just to get them familiar with the programming environment. This program blinked LED's on and off in one second intervals on the digital output. The PVD block diagram program is shown in Figure 3.5. This program demonstrated two programming blocks not seen in the other examples. These blocks were the one-second delay and the digital output. These examples and the sample program were intended to help orient students with the PVD software, the project box, and several sensors and actuators.

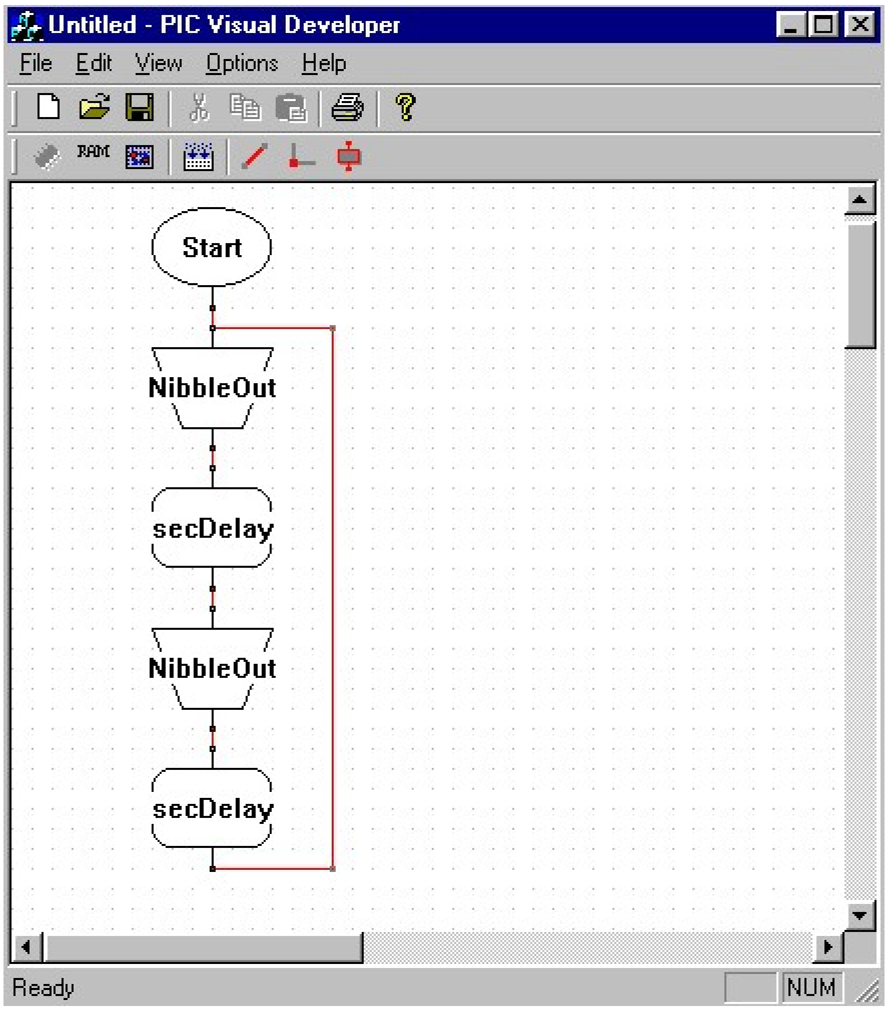

Figure 3.5: Example programmed by the students

3.2.3 Projects

When it came time for the students to prototype their final product design, six design teams inquired about the mechatronics prototyping hardware. The projects were constant temperature/pressure showerhead, a bird deterrent system for vineyards, an efficient dorm fan, automatic headlight tilt mechanism, public washer/dryer security system, and a car locator. Three of the six projects were finally prototyped: the bird deterrent system for vineyards, the efficient dorm fan, and the automatic headlight tilt mechanism.

The concept for the bird deterrent system for vineyards was to create a mobile unit that would travel on a track in a vineyard. The unit would stop at specified time intervals and activate a motion sensor. The motion sensor would then signal if there was motion. If motion was detected a loudspeaker system would activate in order to scare the birds. Since the terrain varies in the vineyard the motor running the unit would need at least three speeds: slow (downhill), average (flat terrain), and fast (uphill). The project used a switch to mimic a motion detector, a gravity sensitive switch for the terrain decision, and an off-the-shelf loudspeaker system designed for the purpose of deterring birds (supplied by the students). To prove the concept, the microcontroller recognized different terrains using the gravity sensitive switch, then actuated the motor accordingly, and the loudspeaker system was activated when the motion detector switch was tripped.

The motivation for the efficient dormitory fan was that many dormitories do not have a temperature regulation system, thus having a smart fan would give the resident some ability to regulate the temperature. The concept for the efficient dorm fan was to create a smart fan that would open a shutter and turn on when the temperature inside was hotter than the desired temperature and the temperature outside was cooler than the desired temperature. The fan would then run until the temperature inside met the desired temperature, the fan would then turn off and the shutter would close. The proof of concept for this project was through the creation of a mockup that opened a shutter and turned on the fan.

The automatic headlight tilt project was centered on the need to reduce headlight glare in rear-view mirrors. The concept of this project was to have headlights tilt downward the closer the vehicle approached another vehicle. The proof of concept for this project used a potentiometer to mimic a range finding instrument, and a motor that tilted the headlight mockup depending on the distance specified by the potentiometer.

The hardware purchased and developed for the vertical integration of mechatronics was utilized in various ways for each project. The project box and the PVD software were used for all of the prototypes. In the case of the bird deterrent system for vineyards the additional hardware used was the loudspeaker system, a DC motor, a momentary switch to simulate the motion detector, and the gravity sensitive switch. The DC motor was attached to the H-Bridge output, the momentary switch was wired to one of the digital inputs of the project box, the gravity sensitive switch was wired to two of the digital inputs, and the loudspeaker system was ran from one of the digital outputs.

The efficient dormitory fan was constructed of cardboard, used a DC motor to open and close a shutter, used a small fan to demonstrate the cooling, a potentiometer to set the desired temperature, and used two temperature sensing IC's. For this project the DC motor and the fan were connected to the H-bridge output via two relays. The two relays were used to direct the signal to the motor or fan. The two temperature sensing IC's were attached to two channels of the ADC. The potentiometer was attached to another channel of the ADC for a desired reference temperature. The microcontroller was used to read the inside and outside temperatures and to compare their values to the reference temperature determined by the potentiometer. Depending on the values of the potentiometer and the temperature sensing IC's the fan and the DC motor may be activated.

The prototype of the headlight tilt mechanism used two potentiometers, two small light bulbs as headlights, and a DC motor to adjust the headlight angle. The PVD code used was the same as the code for position control example. One potentiometer was used to measure the headlight angle and the other was used to mimic a range finding sensor, i.e. the system input. The mechanism was driven by a DC motor that tilted the light bulbs up and down. The microcontroller then used input of the two potentiometers to drive the motor, and thus controlling the headlight angle.

The bird deterrent system prototype performed as designed and demonstrated the concept of the product. The automatic headlight tilt mechanism also demonstrated the desired concept. The mechanical system for the efficient dormitory fan worked as intended and was demonstrated at the final presentation; however, necessary code for the microcontroller could not be developed in time to demonstrate the entire concept. The PVD code developed for the efficient dormitory fan needed modifications done to the resulting assembly code. The reasons for these modifications was that the logic necessary for the project could not be created using the PVD software. The modifications to the PVD's resulting assembly code could not be completed in time for the final presentation.

At the end of the semester when the final projects were presented two groups from each of the 5 sections of the design course were selected to compete against one another for the best product and presentation. The bird deterrent system was selected as one of the projects to compete. This project received third place among all of the competing teams.

3.3 Survey and Responses

At the close of the semester the PI and the RA composed a list of questions for the students to answer concerning the vertical integration of mechatronics project. The questions and their responses are shown below.

1) What were the advantages and disadvantages of incorporating a mechatronics perspective in this course's curriculum?

The students had the following responses to this question. One student's response was that the rudimentary implementation of the design project with mechatronics put the design process in perspective; it also demonstrated the necessity to perform each step of the design process carefully and to a tangible end. Another response was that the mechatronics approach provided an excellent perspective of what is available in the laboratory for prototype development. Yet another student pointed out that the mechatronics approach promoted greater interest of real world applications of one's knowledge. There were no real disadvantages noted.

2) Why did you choose to work on a mechatronics project?

The reasons students cited for wanting to work on a mechatronics project varied. One reason was to increase their understanding of how the design project would actually function. Another reason was the hands-on implementation and creation of the prototype from a basic design. One student cited that many of today's mechanical devices were augmented by electronics and that it is a good idea to gain exposure to the electronics.

3) Do you have any suggestions for continued inclusion (or not) of a mechatronics perspective in the curriculum of this course?

The students suggested having more time to work on the prototype of their projects, spending more time on mechatronics, and making a mandatory project for the students to complete. They also suggested that doing another example more complicated than the flashing LED would help with the understanding of the PVD software and capabilities of the project box. And another suggestion was that the instructor could use several lectures to allow the students to work in the lab with the project box, the PVD software, sensors, and actuators.

3.4 Assessment of Results

The purpose of this experiment was to expose a percentage of second-year mechanical engineering students at Virginia Tech to the basic ideas that make up mechatronics and to give them hands-on experience by prototyping their final project. Integrating mechatronics into the second-year design class was an effective method for introducing mechatronics to the sophomore student. The use of the PVD software, the project box, the sensors, and the actuators were also instrumental in introducing the students to mechatronics. The students who participated in the prototyping of their projects received the most from this attempt to vertically integrate. These students were able to build their prototype, operate the project box, and make a program that would run their physical prototype. Many of the students who responded to the questionnaire were those who worked on prototypes of their projects. It can be seen from the candid responses to the questionnaire that the inclusion of mechatronics was a success with the students. Many of the students were excited by the opportunity to apply their knowledge to designs in a hands-on way.

Though the results of the experiment were positive, there were several places of difficulty that could not be ignored. The first being that the course syllabus was already full of necessary and required material that could not be neglected for the sake of mechatronics. Another difficulty was the timing of the final design project. The final design project was assigned two weeks before the end of the semester and actual design and construction could not begin until then. The construction and debugging of the prototype was difficult to complete in this allotted time. The final difficulty is that if this was to be incorporated in the entire course (not just two sections) there are not enough resources to accommodate the demand. The resources that would need to be created would be several TA positions for only three weeks of an entire semester, and the amount of hardware that would be required for a large number of students to participate in a mechatronics prototype would be prohibitive in cost and would not be a practical use of resources.

Chapter 4

The Vertical Integration of Mechatronics in ME 3514 – System Dynamics

This chapter is concerned with the vertical integration of mechatronics in ME 3514. The first section discusses the layout and objectives of this course. Understanding the nature of the course that mechatronics is being integrated into is important; because, without understanding the course, integrating mechatronics correctly becomes difficult, if not impossible. After the discussion of the course, the implementation of the vertical integration of mechatronics will be discussed. That section will discuss how mechatronics was incorporated as a design project. This section will also discuss the course material created, the hardware purchased and constructed, and the conducting of the laboratory part of the design project. The final two sections of this chapter detail the results of the survey and the assessment of the success of the vertical integration of mechatronics.

4.1 ME 3514 – System Dynamics

The description for ME 3514, System Dynamics, found in the course catalog is the following:

> Mathematical descriptions of physical systems' behavior including mechanical, electrical, thermal, and fluid systems and their combinations; system descriptions using state variables and transfer functions; analysis of system responses using: convolution integral, frequency response, numerical simulations, and Laplace

transform methods; systems concepts: input-output, causality, and analogies; general process descriptions including first-order, second-order, and time delayed.

4.1.1 Course Philosophy

There are two reasons for including this course in the mechanical engineering curriculum. The first reason is that it introduces students to modeling linear systems. The second reason is to teach the students the tools of linear system analysis. The importance of linear system theory is that it is essential for later courses and is needed in practice.

There are several measurable learning objectives for ME 3514. One objective is to be able to separate a physical system into subsystems and identify the appropriate physical principles governing these subsystems. Another objective is that the students should be able to write the governing differential and algebraic equations that describe the dynamics of each subsystem and the physical interconnections between the subsystems. The students should be able to solve and interpret the resulting dynamic equations, and express these equations in the time and frequency domain; both numerical and analytical solutions are found for the dynamic equations. Another objective is to be able to predict the responses of both first and second order systems without solving the resulting linear ordinary differential equations. The students should also be able to describe analogous behavior of various systems; e.g. electrical and mechanical analogies. A final learning objective was for the students to be able to develop and use state-variable and transfer-function descriptions of systems to analyze their behavior.

The following topics are coved in this course in the corresponding percentages:

Topic	Percentage
Differential equations, Laplace transforms	20
Matrix analysis	10
System model representation	15

Mechanical systems	15
Electrical systems	10
Fluid and thermal systems	10
System response	15
Computational instruction	5

4.2 Implementing the Vertical Integration

4.2.1 Incorporating Mechatronics

Mechatronics was incorporated into the course as a design project. The objectives for the vertical integration of mechatronics into ME 3514 and the design project were the following:

- Introduce students to mechatronics
- Increase the students' understanding of system response
- Increase the students' understanding of the final value theorem
- Give the students a tangible experience with signals and systems
- Allow the students to gain more familiarity with the Matlab/Simulink program

The design project assignment was to simulate the steady-state velocity of a DC motor using the Matlab/Simulink program and to compare the simulation results to measured steady-state velocities of a DC motor. To introduce the students to the design project and mechatronics, a PowerPoint lecture was presented to the classes (this lecture appears in Appendix III-A). The lecture presented the basics of mechatronics, the mechatronics course at Virginia Tech, and information on the design project. The students used a transfer function model that was based on a description provided for the specific DC motor. A motor speed controller was created using the PIC Visual Developer software, and was used to generate experimental data in the lab. The experimental data measured by the students was the steady state velocities of the DC motor as a function of PWM duty cycle. A relationship between the duty cycle of a PWM input and the voltage reading from a tachometer measuring shaft velocity was indicated by the resulting data. Students were able to compare the modeled predictions of steady-state shaft velocities versus the actual steady-state shaft velocities, as a function of PWM duty cycle. The final value theorem was also used to approximate the motor shaft steady-state velocity for comparison to the simulated and measured values. A project report was required that provided a brief analysis of the comparisons and the algebraic development of the motor's steady-state velocity using the final value theorem.

4.2.2 Course material

The PowerPoint presentation, lab manual, a motor model handout, and the design project assignment were distributed in the lecture. The lecture presented to the class covered the design project and mechatronics. The lecture introduced mechatronics by giving a definition of it and giving several examples of products that are mechatronic in nature. A brief overview of the mechatronics course at Virginia Tech was given to the students. Next, the students were introduced to the VT84 board, the PVD software, and the project box. The design project was introduced and a detailed discussion of the design project finished the lecture. At the end of the lecture the design project assignment was distributed to the students, along with a handout on the motor model. (All of the handouts mentioned in this section can be found in Appendix III)

The motor model handout discussed the derivation of the motor model transfer function. The derivation presented in the handout follows.

For an armature controlled DC motor the armature voltage is

$$V_a = L_a \frac{di_a}{dt} + R_a i_a + V_b \qquad 4.1$$

where L_a is the armature inductance, R_a is the armature resistance, i_a is the armature current, and V_b is the back-emf. Noteing that

$$V_b = K_b \dot{\theta} \qquad 4.2$$

Where K_b is the back-emf constant, and $\dot{\theta}$ is the shaft speed. The torques are balanced in the following equation

$$J\ddot{\theta} + b\dot{\theta} = K_T i_a \qquad 4.3$$

Where J is the rotor inertia, b is a viscous damping term, and K_T is the Torque constant. Then, substituting 4.2 into 4.1 and taking the Laplace transform

$$V_a(s) = sL_a I_a(s) + R_a I_a(s) + K_b \dot{\theta} \qquad 4.4$$

Then, taking the Laplace transform of 4.3 is

$$sJ\dot{\theta}(s) + b\dot{\theta}(s) = K_T I_a(s) \qquad 4.5$$

Solving 4.5 for $I_a(s)$ and substituting this into 4.4 the following is obtained

$$V_a(s) = \dot{\theta}(s)\left(\frac{(R + sL)(sJ + b) + K_b K_T}{K_T}\right) \qquad 4.6$$

Then the transfer function is

$$G_m(s) = \frac{\dot{\theta}(s)}{V_a(s)} = \left(\frac{K_T}{(R + sL)(sJ + b) + K_b K_T}\right) \qquad 4.7$$

There are two representations that can be used, one using the damping term and another letting the damping term go to zero.

$$G_m(s) = \frac{K_T}{LJs^2 + RJs + K_b K_T} \qquad 4.8$$

This derivation can be found in Phillips and Harbor.

Using this transfer function the students created the simulink model necessary to simulate the steady-state motor velocity. The simulink program the students created was similar to that of figure 4.1. The simplicity of the program was to allow the student to gain familiarity with program without intimidation. The values used for the parameters in the motor model were given in the lab manual.

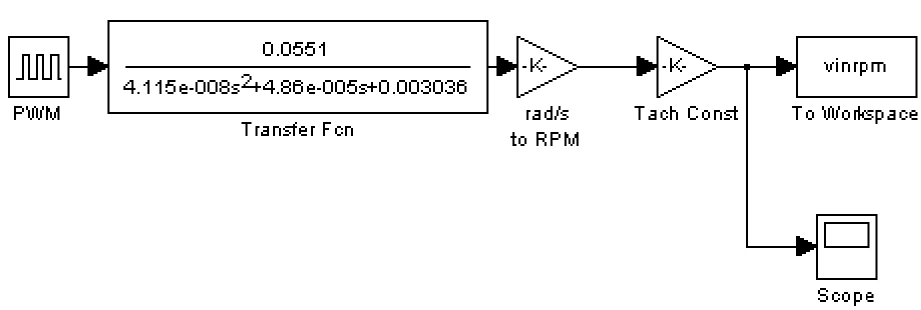

Figure 4.1: An example of the Simulink program created for the design project

The purpose of the lab manual was to walk the students through the laboratory experience. The manual for the laboratory provided definitions for some unfamiliar terms. The terms defined include: microprocessor, pulse-width modulation, potentiometer, and tachometer. A brief description of the PVD software was given in the manual. Step-by-step instructions for the creation of the PVD program for the design project were in the manual. Section 2.3.3 contains a detailed description of this program. The lab manual also detailed the procedure for downloading the program to the project box. The necessary connections and procedures for connecting power to the project box and motor stand were included in the manual. The manual also included all of the necessary diagrams of the project box and motor stand. And a procedure for collecting the data was also contained in the manual. (Appendix III-C: Lab Manual)

4.2.3 Hardware

A motor with an integral tachometer was specified for the lab. The necessary requirements for the motor were that it not be a gear motor, no less than a 12-volt DC motor, and have a tachometer range from approximately 0-volts to 5-volts. A gear motor was undesirable because of the possible nonlinearities that can be added with a gearhead, e.g. backlash. Since the output of the H-bridge is 12-volts, the minimum motor voltage rating was 12-volts. The motor chose to use in the lab was the Pittman 14202 permanent magnet DC motor with integral tachometer (Figure 4.2). Five of these motors were purchased from a parts surplus dealer. Two of the motors were mounted to stands constructed to support the motors along with a potentiometer, a power connection for the potentiometer, and an output for the tachometer (Figure 4.3).

Figure 4.2: DC motor used in ME 3514 design project

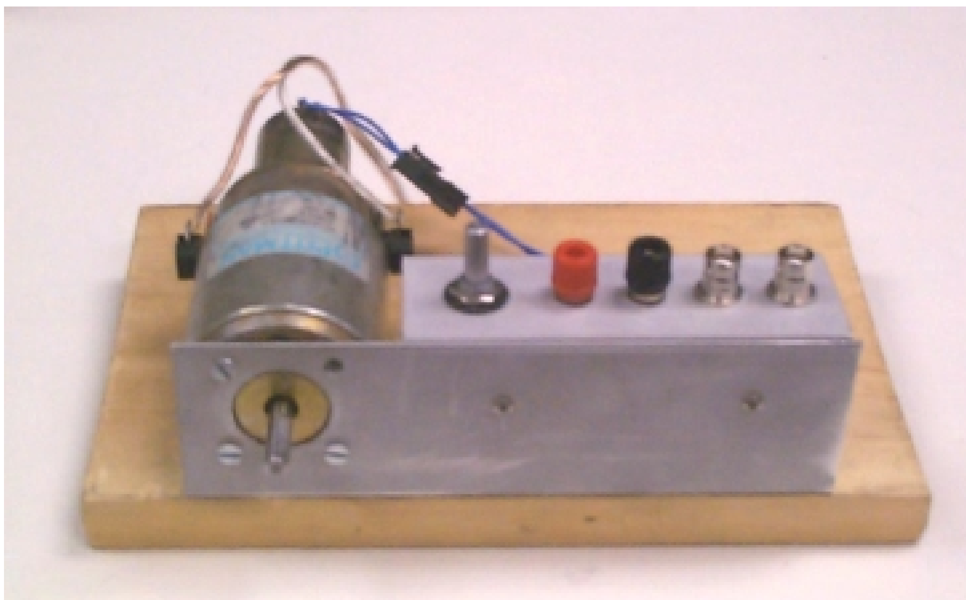

Figure 4.3: Motor stand created for the ME 3514 design project

One modification was made to the VT Project Box for this lab. One of the ground pins provided for the output was converted to a PWM signal output. The ground could be changed because any of the other grounds on the screw terminal could be used for that output's ground. This was done because of an impedance mismatch that occurs when trying to read the PWM signal from the H-bridge output. The impedance mismatch causes the power supply to saturate and changes the signal to the motor. The PWM signal used was that of the PIC since the PIC sends the signal to the H-bridge.

4.2.4 Conducting the laboratory exercise

One-hundred sixty students completed the lab in a one week period. The manner in which this was accomplished was to have four students working at a station a time, and two stations operating at the same time. Assuming approximately one hour for each group of four, the total time for completion of the lab approximately twenty hours. A sign-up sheet was made for the groups to choose a time to complete the lab portion of the design project.

The lab portion of the design project was conducted slightly altered from the procedures in the manual. Instead of the students making the necessary connections to the box and motor stand, the RA already made the connections. Pre-connecting these made it possible for all groups to complete the data collection within an hour, without the pre-connection some groups would have used more than an hour. At the beginning of the hour the students started work at the two workstations, they constructed the PVD program and downloaded it to the project box. Then, the RA discussed with the students how to collect the necessary data. Next, the students collected the data from the tachometer. After the data collection was finished, the RA demonstrated how the motor acts on the PWM signal by showing the tachometer output on an oscilloscope. The output of the tachometer showed variations in the speed of small magnitudes, corresponding to the rise and fall of the PWM signal. The RA also discussed the simulink model with the groups, and how the model was to be compared to the actual data. Though much of the latter information was already conveyed in the lecture, this provided a chance for the students to ask questions on the material, in a setting that is usually not afforded in classroom lectures.

4.3 Survey Results

At the close of the semester a survey was given to gauge the reception of the vertical integration of mechatronics by the students. The survey was given in an op-scan format. The possible responses were from one to five. The following scale was used in the responses of the questions:

1 = I agree very strongly
2 = I agree
3 = I have no opinion
4 = I disagree
5 = I disagree very strongly.

The results of the survey are in the following charts. The survey as presented to the students and the raw data can be found in Appendix III.

In Figure 4.4 the results to statement 1 are shown. Statement one is the following: My interest in mechatronics was increased by participating in the mechatronics lab for DP2. The results of the response shows that the students agreed with the statement.

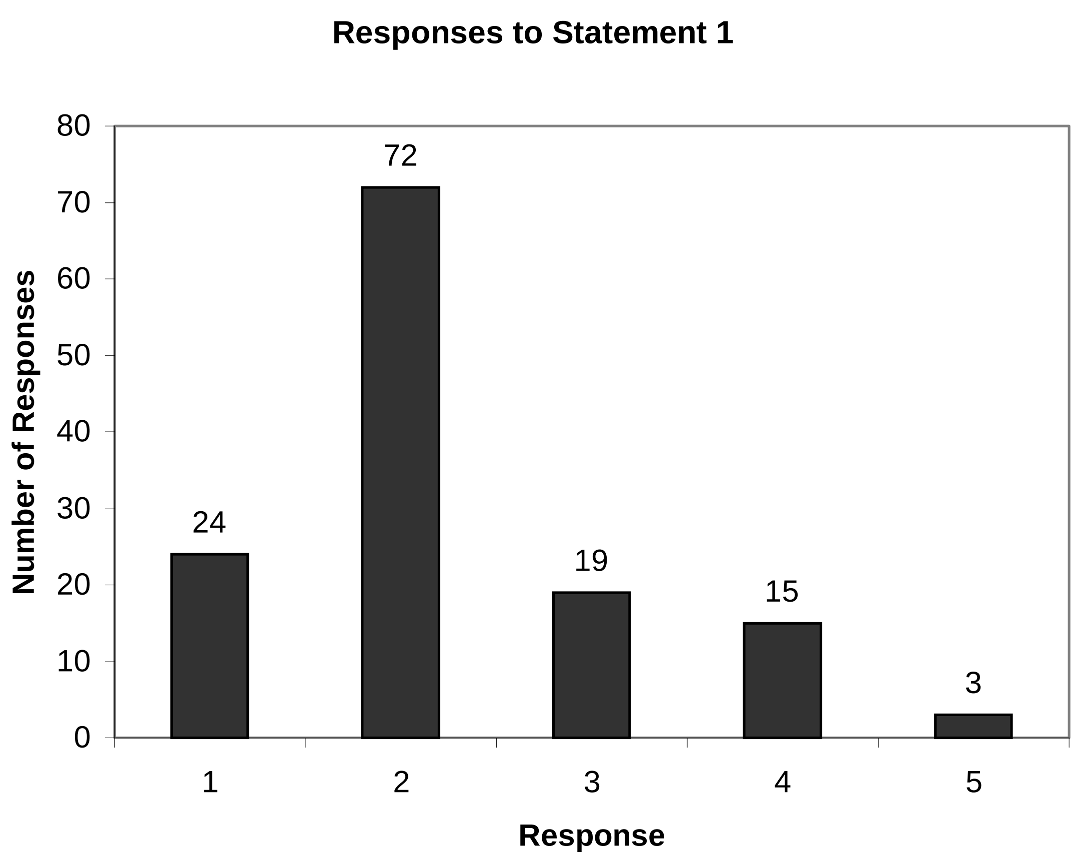

Figure 4.4: Results of ME 3514 survey statement 1

In Figure 4.5 the results to statement 2 are shown. Statement two is the following: my understanding of the ME3514 course material was increased because of the nature of the mechatronics DP2 assignment. The results of the response shows that the students agreed with the statement.

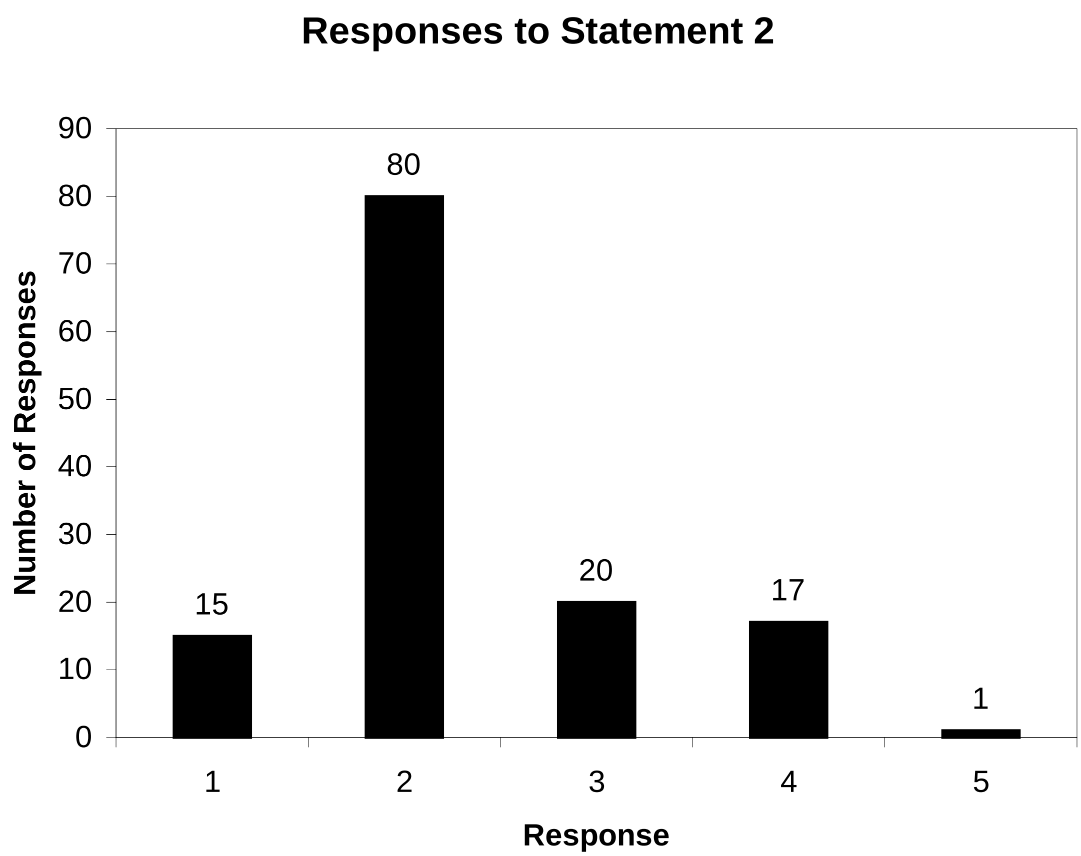

Figure 4.5: Results of ME 3514 survey statement 2

In Figure 4.6 the results to statement 3 are shown. Statement three is the following: the DP2 laboratory instructions provided enough information to allow completion of the lab without a TA, if necessary. The results of the response shows that the students agreed with the statement.

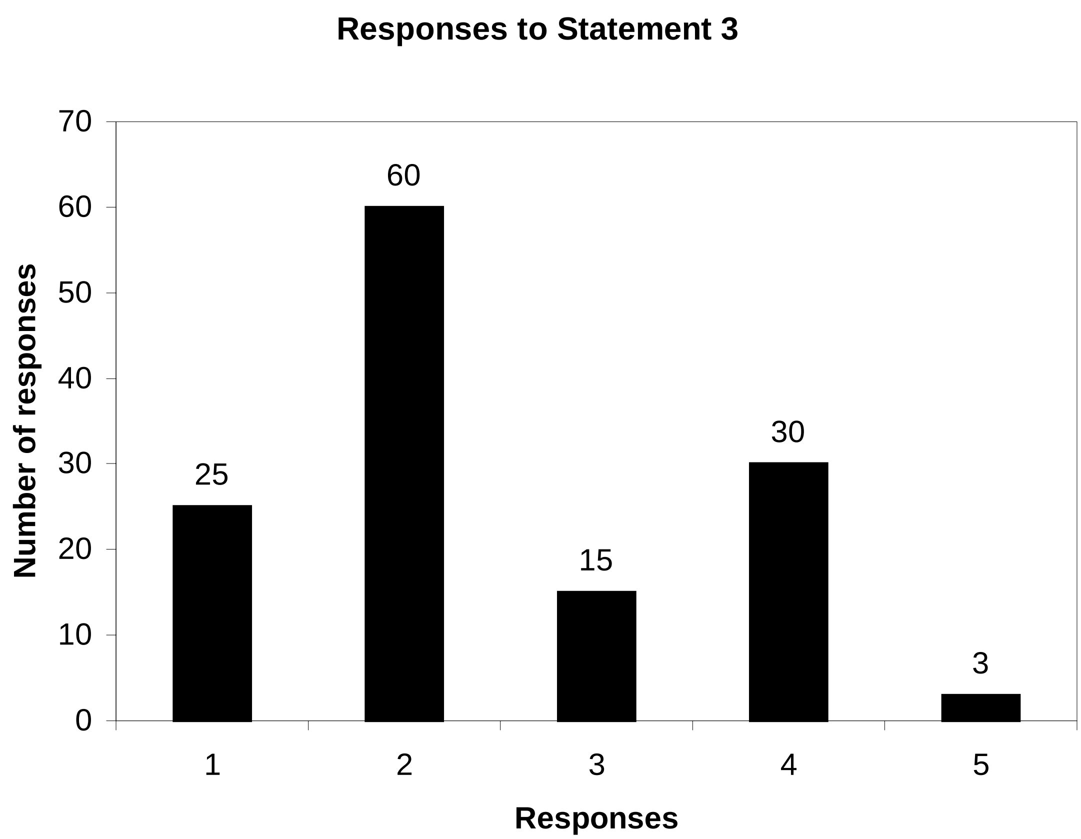

Figure 4.6: Results of ME 3514 survey Question 3

In Figure 4.7 the results to statement 4 are shown. Statement four is the following: The lecture material presented for the mechatronics DP2 assignment and lab project provided sufficient information for successful completion of the assignment's tasks. The results of the response shows that the students agreed with the statement.

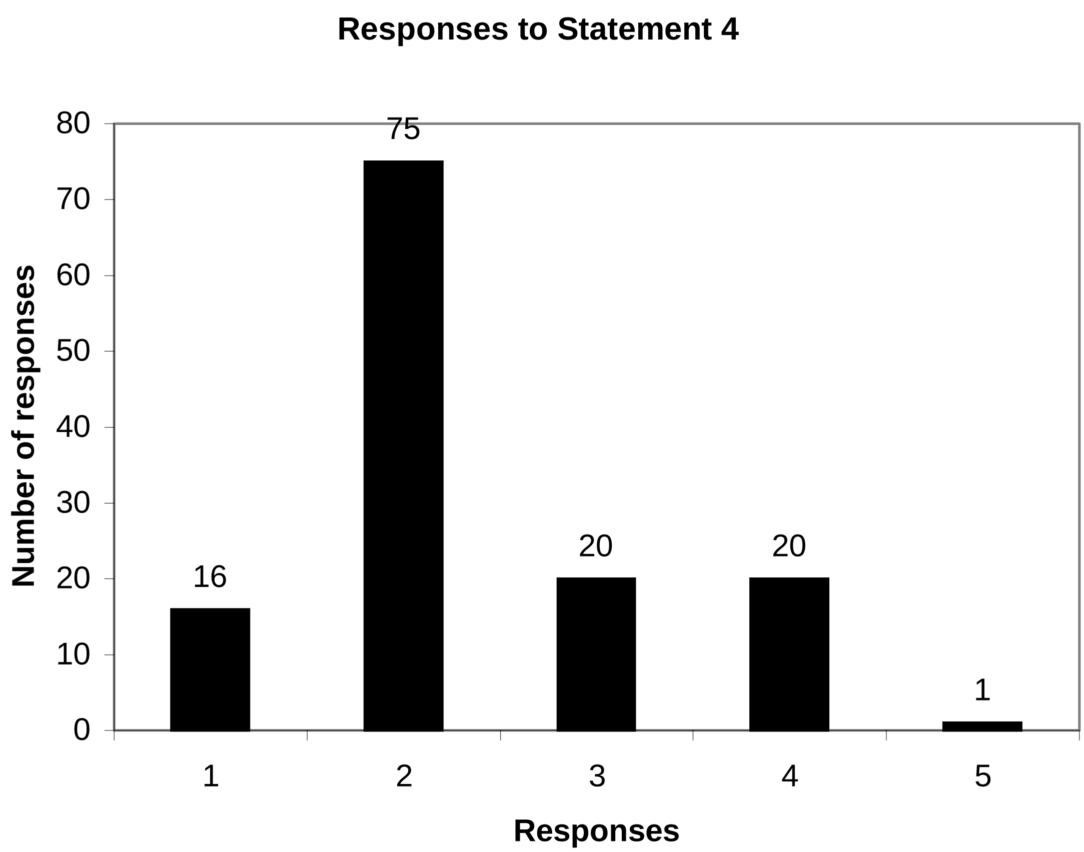

Figure 4.7: Results of ME 3514 survey Question 4

In Figure 4.8 the results to statement 5 are shown. Statement five is the following: the experimental portion of DP2 significantly improved how much I learned from the design project assignment. The results of the response shows that the students agreed with the statement.

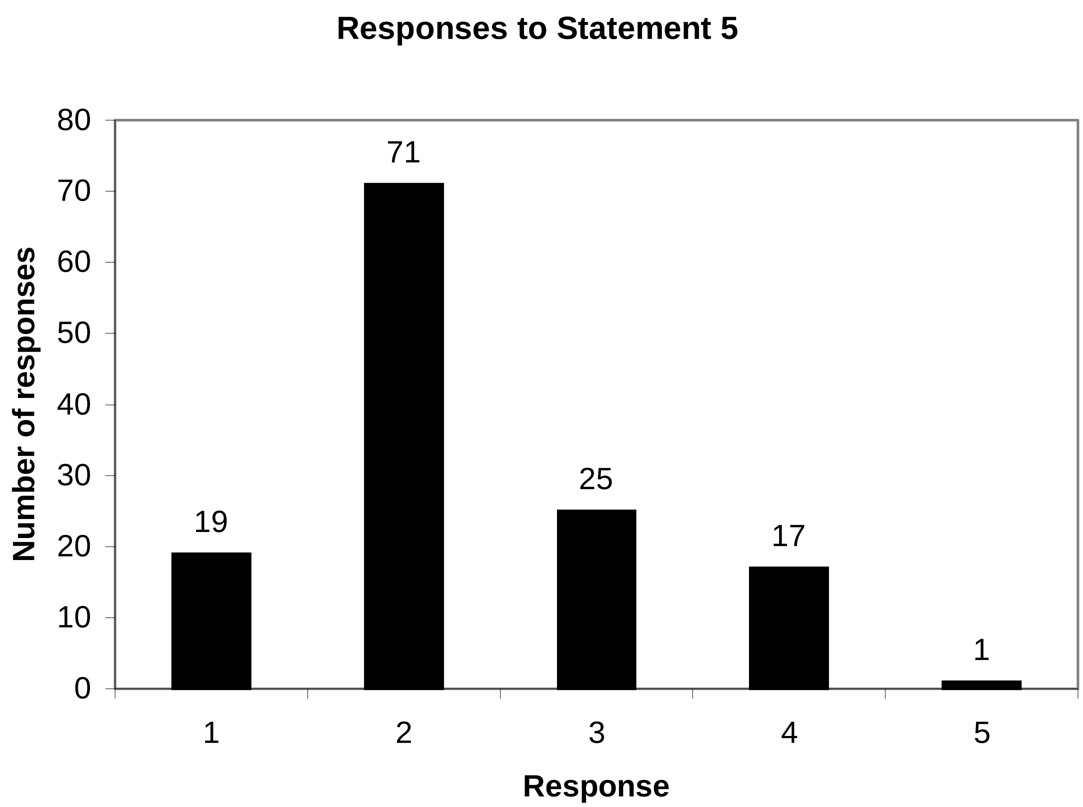

Figure 4.8: Results of ME 3514 survey Question 5

4.4 Assessment of Results

The results of the vertical integration of mechatronics into ME 3514 were successful. The objectives set forth for the vertical integration of mechatronics in ME 3514 were met. The objective of introducing the students to mechatronics was achieved in the class lecture and in the laboratory. From the survey in Figure 4.4 it was shown that the students interest in mechatronics was increased because of the design project. From the survey of Figure 4.5 it was shown that the majority of the students' understanding of the course material was increased because of the inclusion of mechatronics. The students were required to include a calculation using the final value theorem in their design project report; thus demonstrating their understanding of its application. The objective of giving the students a tangible experience with signals and systems was also accomplished by the nature of the laboratory exercise they completed for the design project. Since a comparison of simulation and data was required the students gained more familiarity with the Matlab/Simulink software. The only drawback of the course was the fact that it was only once in an entire semester that the students were exposed to mechatronics.

Chapter 5

Conclusions and Future Work

In this chapter a summary of the thesis will be presented along with the author's view of the future work that is needed in the vertical integration of mechatronics. A summary of the tasks and solutions will be presented. A summation of the vertical integration of mechatronics into ME 2024 and ME 3514 will also be presented.

5.1 Summary of Completed Tasks and Project Solutions

There were several tasks that needed to be addressed in the vertical integration of mechatronics. These tasks included determining what course would be appropriate for the integration, how to integrate within existing courses, what content should be included, how would the success be measured, and what materials needed to be created.

After determining how to integrate mechatronics, it was necessary to determine what content should be included. The content was partly dependent on the course, but the important information to convey would be the essentials of mechatronics. A laboratory exercise was included because it communicates the essential elements of mechatronics. Interfacing a microcontroller to other systems and programming the microcontroller were necessary to communicate the essentials of mechatronics in the lab. The lecture portion incorporated in the course would be several lectures, or demonstrations and examples. The choice between these two was determined by the course. The courses to integrate mechatronics into were selected by the typical approaches to mechatronics: a design methodology or as dynamic systems. With these two approaches in mind it was determined to vertically integrate mechatronics into ME 2024, Introduction to Engineering Design and Economics, or ME 3514, System Dynamics. This was attempted in ME 2024 first because mechatronics is a design philosophy. After the integration into ME 2024, mechatronics was integrated into ME 3514. The success in each of these courses was measured by student surveys and objective assessment of the learning improvements by the instructor/RA. In order to create the necessary laboratory experiences for the vertical integration of mechatronics, a project box and custom software were developed to make it possible for sophomores or juniors to use the tools of mechatronics.

The project box, the VT Project Box, was designed and constructed specifically for use in the vertical integration of mechatronics. The box was built around the VT84 prototyping board. Constructing the box around the VT84 allowed the use of a wide variety of sensors and actuators. The sensors could be analog or digital, and the actuators could be digital or accept a PWM signal to drive the actuator in an analog fashion. The PVD software created to work with the project box was essential to allow the students to easily program the box. The software utilized all of the input/output functions of the box, making the software flexible in the type of programs that could be created by PVD. The PVD software was easy to use because the programs were created using a block-diagram environment.

5.2 Summary of the Vertical Integration of Mechatronics into ME 2024

In integrating mechatronics into ME 2024, understanding the course objectives and class format is important. The purpose of the course is to introduce the design process and the economics of design. The format of the class is teamwork on all assignments except for tests. There are five design projects throughout the class. The desired end result of the last three design projects is the design of a product. For the fifth design project the students are encouraged to create a prototype to demonstrate the concept of their product. Mechatronics was incorporated in the design projects by encouraging the students to include mechatronics in their product design. The students who incorporated mechatronics in their project could approach the RA (Research Assistant) and together they would work on creating a mechatronics prototype using the PVD software and the project box. Mechatronics was integrated into the lectures through demonstrations of the PVD software and the project box, and examples of mechatronics products. The demonstrations and examples were used to give the students the general concept of a mechatronics product. The design projects prototyped were a bird deterrent system for vineyards, an efficient dorm fan, and an automatic headlight tilt.

The bird deterrent system won third place in a competition between all of the students enrolled in that course (approximately 120 students). At the end of the semester the students who prototyped a mechatronics product were surveyed. The students cited no disadvantages in the integration of mechatronics and several advantages. The advantages were that the mechatronics prototype put the design process in perspective, showed the available lab equipment, and demonstrated real world application of the design process. The students cited that they chose to do a mechatronics project because it was hands-on and many of the modern mechanical systems are integrated with electronics. In the survey the students suggested making the mechatronics part mandatory and allowing more time.

The ME 2024 course was an appropriate place for the vertical integration of mechatronics, because the course emphasizes design methodologies and mechatronics is a design philosophy. The timing of the final project was poor, so student participation in the final project was low. One essential part of the vertical integration of mechatronics was the lab experience. The only students who participated in the lab were the students that created a mechatronics prototype. All of the students in these sections were introduced to mechatronics concepts in the lecture; thus disseminating the concepts to the entire class. The entire class was not surveyed to see the impact of the inclusion of mechatronics in the lecture. The final results of the vertical integration are not truly known because of this. The survey responses for the class were limited to those who participated in a mechatronics prototype, and the response to these were positive.

5.3 Summary of the Vertical Integration of Mechatronics into ME 3514

Integrating mechatronics into ME 3514 requires an understanding of the course objectives. The main objectives of the course are to introduce system modeling using various mathematical methods and to cover the interactions of various systems. Mechatronics was added to this course as a mandatory part of a design project. The design project was to make a motor model with Simulink and compare the model to actual data from the motor. Two lectures were given covering the material and the students collected the data in the mechatronics laboratory using the PVD software and the project box. The material created for the course included a PowerPoint presentation describing mechatronics and the design project. Other course material created for the course included a derivation of the motor model and a lab manual that detailed how to collect the data. All of the material was provided to the students. Pittman motors with integral tachometers were purchased to carry out the laboratory experiment, and motor stands were constructed to mount the motors. The students used the PVD software to create an open-loop speed control for the motor. The speed control used the PWM from the H-bridge to control the speed of the motor. The students recorded various speeds corresponding to different duty cycles. Then, the students ran their Simulink simulations and compared the results of the model to the data collected. The students submitted their results and conclusions in a memo.

At the end of the semester a survey was distributed to the students. The results indicated that the students' interest in mechatronics was increased. The survey also indicated that understanding of the course material was increased by the inclusion of the mechatronics. The results of the survey also indicated that the experimental potion of the design project improved the students learning. The success of the vertical integration of mechatronics can be seen from these results. Unlike ME 2024 the timing for the integration was good, and mechatronics reached all of the students enrolled in the course. This attempt was more successful because the material was integrated as an entire lecture.

Also, the entire class was able to participate in a laboratory experience; which is an important part of the vertical integration.

5.4 The Near Future for the Vertical Integration

The near future of the vertical integration is promising in several respects. The vertical integration of mechatronics was successful in the ME 3514 course, so it has been decided that the design project will be included again in the Spring 2001 term. The information in this thesis pertaining to the vertical integration of mechatronics in ME 2024 will be presented at the 2001 ASEE annual conference. The dissemination of the mechatronics hardware and software created for the vertical integration to other universities will be a driving force in the following year. The dissemination will allow other universities to vertically integrate mechatronics into their curriculums as well. Also, in the following year the mechatronics design project in ME 3514 will become a permanent addition to the course. Approximately 180 juniors will be exposed to mechatronics every year, due to this method of integration.

5.5 An Ideal Vertical Integration Approach

In an ideal world, the vertical integration of mechatronics would take place as a course of its own. The course would occur during the first junior semester with ME 3514 as a co-requisite. Also, the course would be team taught by ME and ECE faculty. The course would build off of the material presented in ME 2024 and ME 3514 by combining it together and concentrating on mechatronics. The course would require a laboratory session. The students would work as teams on all of the projects and in the laboratory session. The lecture portion of the course would include in-depth discussion of electro-mechanical system interaction and in particular simulating a microcontroller. A general coverage of available microcontrollers and the capabilities of the microcontrollers should be covered in the lecture. Product design using mechatronics should be taught. In order to emphasize product design, the students would be required to complete design projects relating to product design. These design projects would be open-ended similar to those in ME 2024. There would be approximately five structured labs conducted similar to ME 4005. The labs should include reverse engineering of mechatronics products currently on the market. The lab should also introduce students to a mechatronics prototyping package such as one of the following:

PVD software and the VT Project Box

LEGO © mindstorms

DSPACE/SimuLink package

Another lab exercise could be interfacing the package to various mechanical systems and conducting experiments as in the vertical integration of mechatronics in ME 3514. After each lab, the student groups should submit a one-page memo detailing the results of the lab.

Several issues would have to be considered for this course to be integrated into the curriculum. The course would need to be a technical elective for the students, therefore considering the courses' fit into the existing curriculum would be necessary. Also, the course would have to be approved by the Department of Mechanical Engineering and the University. Funding for the instructor and the necessary TA's would also have to be acquired, whether through grants or from the department. Course material would need to be created for the course. This endeavor could be feasible given enough interest from the students and faculty.

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