# Introductory Mechatronics Course Created to Fulfill Freshman-Level Engineering Requirement

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## Introduction

Although mechatronics education is well established in Europe and Asia, in the United States it has been largely confined to specific interest areas in electrical or mechanical engineering graduate programs. Recently, more U.S. engineering schools have begun incorporating mechatronics as an optional senior design course or as a component to an electromechanical energy conversion course. The specific course described in this paper was developed to meet ABET's introductory engineering accreditation requirement and designed specifically for N.C. State University's Bachelor of Science in Engineering with a Mechatronics Concentration at its off-campus site on UNC-Asheville. The mechatronics program, a multi-disciplinary curriculum, requires students to take classes in electrical engineering, mechanical engineering, and computer science to gain a wider understanding of smart (i.e., computer-controlled) systems and devices. The course uses Parallax's Boe-Bot to teach students basic microcontroller concepts. The students also learn about basic electrical engineering concepts such as Ohm's law, power consumption, simple motor fundamentals, wiring techniques, and components. The course may also serve as an interesting introductory course in a mechanical engineering, an electrical engineering, or a computer science program. The two-credit-hour course has been offered twice -- Spring Semesters 2001 and 2002. The course's philosophy and learning platform, objectives and assignments, structure, and student evaluation are summarized in this work.

## Philosophy and Learning Platform

The course provides students with the opportunity to build simple electrical circuits and make intelligent decisions based on sensory input. Sensory input can range from the status of a push button to ambient light level. In several exercises, servomotors are used to effect robotic motion. The hands-on course is a confidence builder for students with little hands-on experience. Most students feel the satisfaction gained by achieving the desired physical result, whether the result is a robot behaving in a certain manner or a message scrolling across a liquid crystal display (LCD). The "fun" element of the course further sparks student interest in engineering. Moreover, as in the case of the "piano" assignment, the tasks assigned in this course can be similar or identical to projects assigned in senior level courses – the difference is the level of detail which must be addressed.



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The Boe-Bot, or Board of Education Robot, consists of a Board of Education mounted on a metal chasis housing two servomotors driving plastic wheels and a third polyethylene ball for stability. The Board of Education, developed by Parallax Inc., features a custom PIC16C57 programmed with a PBASIC2 instruction set and a 2 KB EEPROM. A PBASIC program, written using a PBASIC editor loaded on a personal computer, is downloaded to the EEPROM through a serial cable. The Board of Education also features a prototyping area with a small breadboard and sockets connecting to power, ground, and the microcontroller's 16 input/output pins. The PBASIC language is quite programmer friendly and the PBASIC2 instruction set features specialized commands which simplify interfacing the microcontroller with the external world. Several of the custom commands frequently used in the course and their functions are listed in Table 1.

**Table 1. Specialized PBASIC Commands**

| COMMAND | FUNCTION | EXAMPLE APPLICATION |
|---|---|---|
| Freqout | Generates one or two sine-wave tones for a specific duration. | Speaker sound |
| Pulsout | Outputs a pulse for a specific duration. | Servomotor operation |
| Rctime | Counts time that pin remains is a specific state, usually for measuring the charge/discharge time of a resistor-capacitor circuit. | Measure light intensity with a photoresistor or temperature with an analog temperature probe. |
| Shiftin<br>Shiftout | Shifts data in/out of a synchronous-serial device. | Communication with digital temperature chip |
| Serout | Transmits asynchronous data. | Communication to LCD |

Although the two-credit-hour course originally began as a series of two one-credit-hour laboratories based on Parallax's educational manuals [1,2,3,4,5] downloadable from their website [6], the course's lectures and assignments have evolved into a unique learning experience.

**Content Objectives and Synopsis of Course Assignments**

The course has two main content objectives: (a) to promote awareness of the ubiquitous presence of smart devices and systems in the home, office, and industry, and (b) to provide a rudimentary understanding of their operation. The key aspects of mechatronics [7] are shown in Figure 1; computer control of devices based on sensory input is the focus of this course. Table 2 lists the main topic addressed by each assignment. Each assignment consists of several parts, often requiring a program and a schematic. Occasionally questions are included in the assignments to ensure that students understand the material or to simulate simple engineering decisions. The initial tasks required in an assignment are usually building blocks for the final task. The following paragraphs discuss the central aspects of assignments required for the course taught during Spring 2002. Appendix A lists components, in addition to the Boe-Bot Full Kit, needed to complete the assignments.

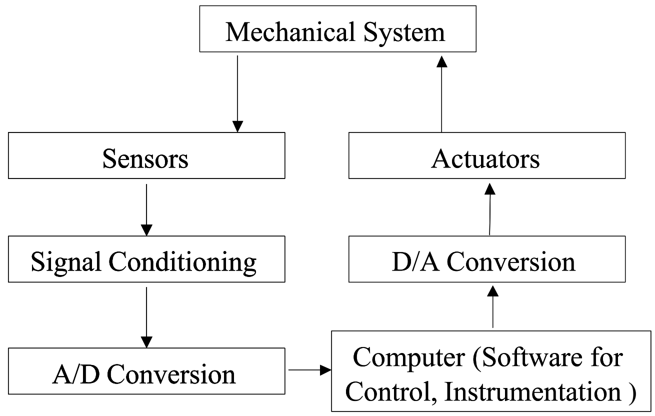


**Figure 1. Mechatronic System**

**Table 2. Assignment Topics**

| Assignment | Main Topic |
|---|---|
| 1 | Introduction to Digital Control |
| 2 | Introduction to Digital Storage and Retrieval |
| 3 | Manual and Automatic Processes |
| 4 | Actuation and Motion |
| 5 | Object Detection and Avoidance |
| 6 | Introduction to Digital and Analog Devices |

The course begins with an introduction to mechatronics, embedded systems, microprocessors, microcontrollers and PBASIC. The first assignment demonstrates that a microprocessor can govern physical actions according to physical inputs. Students are required to develop a flashing visible pattern from green, yellow, and red light-emitting diodes (LEDs) similar to patterns observed from a traffic light. Then the students are directed to change the timing pattern to one that they think would improve traffic flow. Two push buttons are used; one push button initiates the original pattern, the other initiates the preferred pattern, and pressing both push buttons causes the three LEDs to blink on and off simultaneously. One student's traffic light is shown in Figure 2.

Assignment 2, an electronic "piano," is an introduction to memory and data storage and retrieval. To generate the notes C, D, E, and G, four push buttons are used. A program is written to play a note for some pre-determined time when the corresponding push button is pressed. After a fifth push button is added and the program is modified, the fifth push button initiates a playing of the note sequence since the last re-play or power start-up. Finally the program is modified so that the playing time of each note is stored. The "piano" can now play and remember simple tunes.

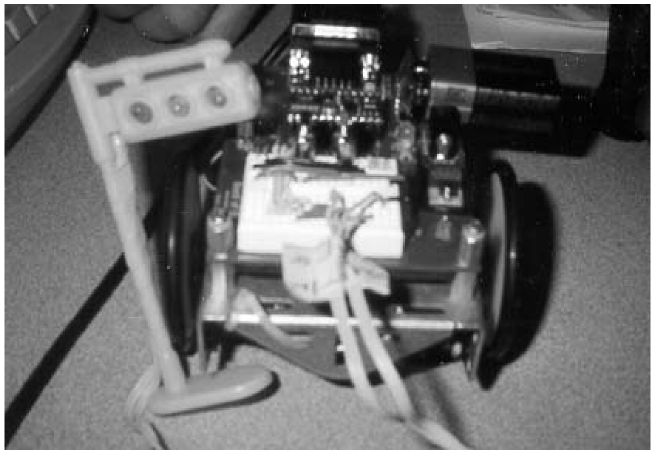

**Figure 2. Traffic Light, Assignment 1**

In the third assignment, students are required to design a manual process controlled by a push button and an automatic process controlled by a light sensor. An elevator's interior "hold door open" and "hold door closed" buttons and an exterior "open elevator door" button are simulated with three push buttons. A servomotor is used to represent control of the elevator door. The button operation has a hierarchy of interior open, interior close, and exterior open; pressing a button higher on the hierarchy interrupts lower-hierarchy-button operation. In the second part of Assignment 3, a servomotor is used to simulate a motor automatically adjusting the window blind angle in an art museum, in response to changes in sunlight. First the students are asked to evaluate the sensitivity of a photodiode and a photoresistor and choose a photosensor based on performance and cost. One student attached a pencil to his servomotor, as shown in Figure 3, so that incremental changes in the servomotor's shaft could be easily observed.

In the fourth and fifth assignments, servomotors modified for continuous rotation are

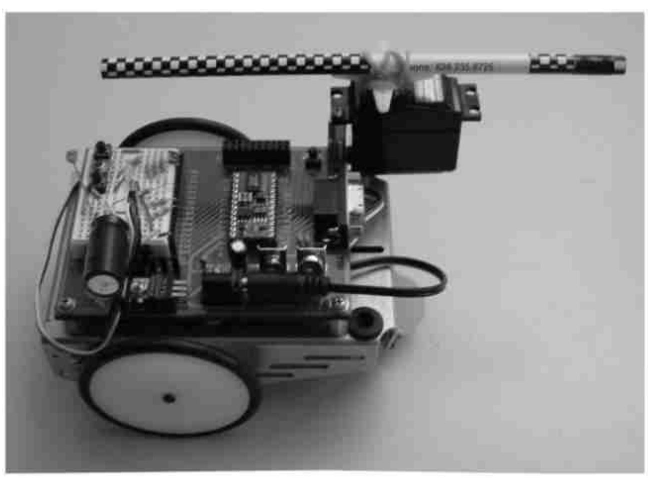

**Figure 3. Boe-Bot Equpped for Assignment 3**

used to drive the Boe-Bot. In Assignment 4, analogous to automobile movement, the Boe-Bot is required to drive at specific speeds around a city block (square), a roundabout (circle), and an equilateral triangle. The Boe-Bot must also drive home from memory (EEPROM). In Assignment 5, the Boe-Bot behaves as a purring "cat-bot" obediently following light while attempting to avoid objects with tactile-sensing whiskers. The Boe-Bot behaves as a screeching, green-eyed "owl-bot," which uses infrared sensing to first avoid collisions, but eventually to seek a resting place. The Boe-Bot also behaves as a squeaking, blind "mouse-bot" required to follow a wall without touching it. A Boe-Bot equipped with infrared transmitters and receivers is shown in Figure 4.

**Figure 4. Boe-Bot with Infrared Sensors**

Assignment 6 involves reading air and water temperatures, as well as displaying current conditions on a liquid crystal display. Multiple air and water temperatures are also stored in memory (EEPROM), retrieved, and analyzed. The subroutines for obtaining temperature readings are based on code from the *Earth Measurements* manual.

The five of the six assignments (described above) assigned during Spring 2002, are based on Spring 2001 assignments, although several of them were modified to be more challenging and original. Eight assignments were required when the course was first taught during Spring 2001, but the number of assignments was reduced because the workload seemed heavy for some of the students. The assignments are intended to expose students to many different techniques and components in the framework of better understanding mechatronics.

Assignment 2, the "piano" was first used during Spring 2002 to introduce memory and data storage and retrieval from the EEPROM, which is reinforced in later assignments. The "piano" assignment has reduced the need for the elevator program in Assignment 3, originally the second assignment. Like the "piano," the elevator door program served to reinforce programming techniques without requiring any new hardware. The light-sensing servomotor adjustment program of Assignment 3 will also be replaced. When the course is offered again, the Manual and Automatic Processes assignment will be the last assignment; a pump will be controlled by a keypad (manual process) and by light level (automatic process). The new assignment will give students exposure to using keypads and to pump operation. One of the experiments assigned in one of the original one-credit-hour laboratories was based on an experiment in the *Earth Measurements* manual and required controlling a pump according to the level of ambient light. At night (darkness), the pump worked on an automatic timing cycle; during the day, the pump operated on a hysteresis cycle dependent on water level measurable in conductivity. At any time, the pump could be turned on manually by a push button. The numbers of times the pump was activated by automatic, hysteresis, and manual operations was stored in and retrieved from memory (EEPROM).

**Overview of Course Structure**

The class meets for two hours twice a week. The unconventional ratio of credit hours to in-class hours was selected to integrate traditional lecture-style learning with laboratory experience. The number of credit hours earned equals the number of credit hours given for a one-hour lecture in conjunction with a three-hour lab. Each student is free to select a lab partner with the understanding that both students will receive the same grade on each assignment. The Boe-Bots are not stored in the lab; instead, each group is loaned a Boe-Bot and accessory parts, for which they are responsible. This arrangement is agreeable to most students since it allows them to work on assignments outside class hours.

The course is held in a room equipped with personal computers, Internet access, and a computer-projection system. The class meetings usually begin with a concise 15-minute lecture presented on PowerPoint slides, archived on the course website, which summarizes key points and provides information needed to complete the assignments. Sometimes a markerboard is also used. After the lecture, the instructor is available to assist students with problems they encounter; in addition, the instructor proactively circulates among the working student groups to teach them individually and to stimulate learning.

A student's final grade is determined as follows: two tests each accounting for 15% of the total grade and the assignments, equally weighted, accounting for the remaining 70%. With the allocated point distribution, students are accountable for all required work, yet a single poor grade on a test or an assignment does not significantly impact an otherwise good performance. The tests are given before the withdrawal deadline and at the end of the semester. No final exam is given because students must develop an understanding of mechatronics, the objective of the course, in order to complete the assignments.

A set of six to eight assignments in a semester course with approximately thirty class periods is a compromise between a project-based course and one in which new assignments are completed each class meeting. The introductory students are required to pace themselves to complete work objectives, but are not weighted by the responsibility of a large project. Also, if a group of students produces inadequate work for one assignment, the next assignment provides a fresh start. Although some mastery of the programming language must be acquired early in the semester, it is possible for students to earn high scores on later assignments even if they have received poor grades on earlier assignments.

**Student Evaluation of Course**

Of the 21 students enrolled in the course in 2001, 18 submitted a course evaluation form and 17 of the 19 students enrolled in 2002 completed a course evaluation form. A few key responses from the course evaluation form are listed in Table 3. A rating of 5 is *excellent* and a rating of 1 is *very poor*. Since this course has been designed by the instructor and is not accompanied by a comprehensive text, the course and instructor ratings are somewhat more interdependent than in a traditional course. Student comments about the course are also listed.

**Table 3. Course Evaluation Responses**

| QUESTIONS | SPRING 2002 | | SPRING 2001 | |
|---|---|---|---|---|
| | MEDIAN | MEAN | MEDIAN | MEAN |
| Overall, rate instructor. | 5.0 | 4.4 | 4.5 | 4.3 |
| Overall, rate course. | 4.0 | 4.3 | 4.0 | 4.1 |
| Rate course organization. | 4.0 | 4.3 | 5.0 | 4.5 |
| Did instructor stimulate thinking? | 5.0 | 4.5 | 5.0 | 4.3 |

In response to the question, "What aspects of the course were most beneficial to you?" comments included:

- Understanding many parts of mechatronic systems and how they work. (2001)
- Gained some understanding about the importance of microcontrollers in daily life. (2001)
- I learned a lot about the basics of electronics and an insight into the more complex side of components. (2001)
- Actually brought everything we learned together to do something. (2002)
- I learned a great deal about programming and microprocessor control. (2002)
- Learning how to build simple circuits. (2002)
- Getting used to PBASIC and basic programming, logical thinking and problem solving skills. (2002)
- Mixing hardware and software in one project. (2002)

In response to the question, "What do you suggest to improve this course?" comments included:

- More projects! (2001)
- Too much work, Experiment not very much fun but moving it was fun. (2001)
- Not more moving experiments. (2001)
- There should be a prerequisite course of basic programming and electronics. (2002)

Several remarks from students in the *suggested improvements for course* categories had some merit. For students with little or no programming experience, PBASIC may have been an obstacle that prevented them from learning about mechatronics – the main objective of the course. Perhaps, an introductory programming course should be a prerequisite. A few students may have been overwhelmed by the range and depth of topics that the assignments, and consequently the lectures, addressed. The course contains a variety of assignments since some students prefer robotic exercises ("…moving it was fun") and others prefer those like measuring temperature and displaying the information on an LCD ("not more moving experiments").

The course evaluation responses in Table 3 suggest that students felt like the course was a valuable learning experience, particularly when one of the instructor's goals was to stimulate thinking. From the student responses about the *most beneficial aspects of the course*, it is clear that many students felt like they had really learned about mechatronics.

## Conclusions

The two-credit-hour introductory mechatronics course has achieved its objectives of increasing the awareness and understanding of smart systems and devices. In the United States, mechatronics is traditionally a discipline studied only in specialized electrical or mechanical engineering graduate programs. However, mechatronics can be introduced early in a college curriculum to excite students about engineering. In contrast to learning purely theoretical subjects, when students have the opportunity to apply theoretical concepts and programming techniques to create tangible results, they can more clearly grasp engineering's physical impact on and interaction with the world.

## References


1. *What's a Microcontroller?* Student Guide, V. 1.5, Parallax, Inc., 1999.
2. *Robotics!* Student Guide, V. 1.2, Parallax, Inc., 1999.
3. Ba*sic Analog and Digital* Student Guide, V. 1.0, Parallax, Inc., 1999.
4. *Earth Measurements* Student Guide, V. 1.0, Parallax, Inc., 1999.
5. *Robotics!* Student Guide, V. 1.3, Parallax, Inc., 2000.
6. http://www.parallaxinc.com and http://www.stampsinclass.com.
7. Mohan Krishnan, Shuvra Das, and Sandra A. Yost, "Team-Oriented, Project-Based Instruction in a New Mechatronics Course," *1999 Frontiers in Education Conference Proceedings*, 1999.



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**Appendix A**

All components may be purchased individually from Parallax, Inc. or many other electronics, hobbyists, or educational suppliers. Although specific parts may be listed, many suitable substitutions are available. Parts contained in Parallax's Earth Measurement Parts Kit are indicated by EM.

| | |
|---|---|
| Assn. 1 | 1 green LED – EM<br>1 yellow LED |
| Assn. 2 | 5 push buttons –1 in EM |
| Assn. 3 | 1 un-modified, DC hobby servo motor (Hitech HS 300)<br>3 push buttons – 1 in EM<br>1 photodiode (Photonic Detectors) – EM |
| Assn. 4 & 5 | none |
| Assn. 6 | analog temperature probe (Analog Devices 592) – EM<br>digital thermometer (Dallas Semiconductor, DS1620) – EM<br>2x16 liquid crystal display (BPI-216 LCD module, Scott Edward Electronics, Inc)<br>connector for connecting LCD to Board of Education |
| Old Pump Assn. | pump (Edmund Scientific X50-345) – EM<br>high-gain transistor (Zetex 1049A) – EM<br>push button – EM<br>conductivity probe (plastic piece with 2, 1/8" holes (0.4" apart) drilled for holding screws and 2 screws, at least 1" in length) – EM |
| New Pump Assn. | pump (Edmund Scientific X50-345) – EM<br>high-gain transistor (Zetex 1049A) – EM<br>4x4 keypad (Grayhill, Inc)<br>MEMKey keypad encoder (Solutions Cubed)<br>jumper cable for connecting keypad to encoder<br>connector for connecting encoder to Board of Education |