Incorporating Mobile Robots in a Microcomputer Programming Course

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ABSTRACT

Most Electrical Engineering undergraduate programs require an assembly language programming course for graduation. Such a course is usually taught using a particular microcomputer or microcontroller. At the Air Force Academy, the Motorola 68HC11 microcontroller is used to teach assembly language programming and to introduce the use of embedded microcontrollers in system design. One of the most common challenges for educators who teach this type of course is covering all desirable hardware and software concepts in a single semester. To help remedy this situation, we recently redesigned the course so each student must complete a single mobile robot project with multiple “subsystem labs” replacing the previously unrelated lab sequence. We believe this more integrated approach improves the course for both educators and students while facilitating the development of a systems design methodology.

INTRODUCTION

Typically, a microcomputer assembly language programming course is a required course in most electrical engineering (EE) curricula. Such a course, however, has often been dreaded by many students, mainly due to the numerous details needed to learn a new programming language. These courses usually use a microprocessor or a microcontroller as a test-bed to program and execute assembly language programs. To increase student understanding, labs are designed to help students practice specific assembly language skills while learning specific functions of the microcontroller or microprocessor. An alternative lab approach to such a course provides students with a single large project which is carefully divided into multiple labs and administered throughout the semester. As we will discuss, such a project can provide students with an integrated overview of the hardware along with opportunities to practice desired programming skills.

In this paper we present a case study of integrating a “large” project with an EE microcomputer programming course, which is required for all EE majors at the United States Air Force Academy. The objectives of the course are to teach: 1) assembly language skills; 2) microcontroller hardware; and 3) microcontroller input/output interfacing skills, i.e., interfacing external devices such as a LCD unit, switches, and sensors.
In the past, we have used a sequence of somewhat unrelated laboratory exercises to introduce the assembly language programming skills along with the hardware features of the Motorola 68HC11 microcontroller. Unfortunately, our experience has shown that with this approach many students do not develop a sufficient appreciation for the integrated hardware/software power that a microcontroller provides system designers. To meet this challenge, we introduced a mobile robot project (see Figure 1) through a series of integrated laboratory exercises to 34 students during the Fall 1997 semester. Figure 1 also shows the lunch box sized 68HC11 portable lab unit developed at the Academy\(^1\). In this paper we present the project, observations made by the faculty who designed and administered the course, and student feedback.

In the next section, we describe the merits of the two lab approaches followed by reasons why we advocate the “one big project” approach. We then describe each of the ten labs used in the course to demonstrate how the labs are used to integrate the course objectives and the robot project. Some relevant observations made by both the instructors and the students are then presented, followed by a few concluding remarks.
INDEPENDENT LABS VS. INTEGRATED LABS

The advocates of the first approach, a series of independent labs, argue that independent labs help students to concentrate and master skills related to a limited amount of the course material. Independent labs also work well in a class where not all students successfully complete all the labs. In such cases, students are not necessarily constrained to finish a previous lab to start the next lab. On the other hand, integrated labs provide students with an overall direction, i.e., a road map, for the course. Students can see the “big picture” and understand how each lab fits into the global goal of the course. This approach also encourages students to practice top-down design skills and to organize their work for future use. Integrated labs also force students to better document their software and hardware designs. In addition, the integrated labs allow students to practice system integration skills. Finally, the integrated labs give educators and students a freedom to employ more enjoyable and interesting labs with meaningful real-life applications. Furthermore, the benefits offered by independent labs can be incorporated in the integrated labs as well. For example, while each integrated lab contributes to the overall project, it can still be carefully designed to emphasize particular skills. And by providing standard instructor generated answers in the form of hardware diagrams and program code when necessary, students who do not successfully complete previous labs within a given time period do not continue to fall farther behind (They do incur a grade penalty, however!).

MOBILE ROBOT PROJECT

In this section, we briefly present each of the ten mobile robot labs we used for the microcomputer programming course. For more details on the labs, readers are encouraged to contact the authors. The final objective of the mobile robot project was to create a robot that could move about a maze, find an exit, and successfully move out of the maze. To do so, students had to implement hardware and software for motor control, use a set of IR sensors, and deploy some type of navigational strategy.

- Lab 1: The first lab was used to teach students how to use the hardware platform (68HC11EVB) and the IASM (integrated assembler) software which ran on a PC. The lab guided students through the use of the IASM editor, assembler, and loader. Students were also taught how to use the 68HC11 monitor program called BUFFALO (Bit User Fast Friendly Aid to Logical Operations) to view, modify, and trace microcontroller instructions.

- Lab 2: [The students learned the basic instruction set of the Motorola 68HC11 before this lab started.] During this lab, students wrote a simple program on the 68HC11EVB using some basic instructions as well as “if-then-else” constructs (branch instructions). The lab was later modified to make decisions for the mobile robot based on three infrared sensor values for navigation.

- Lab 3: During this lab, the students practiced how to use subroutines by creating a program which used the two parameter passing methods, call-by-value and call-by-reference, to generate simulated motor speed profiles. The motor speed profiles were later used to actually
control the robot motors. The control scheme used pulse-width-modulated signals to drive two DC motors (wheels).

- Lab 4: Use of the built-in BUFFALO subroutines was taught. The students wrote a program to display the simulated motor control speed profiles (created using lab 3) on a PC screen using appropriate BUFFALO subroutines. The skills learned in this lab were later used in debugging the robot program and to report robot status to a user.

- Lab 5: This lab was designed for students to practice the polling method for detecting an external event. This lab was used to interface an external switch to the microcontroller which in turn activated the program developed in Lab 4. Later, this lab software and hardware were used to start the mobile robot maze navigation program.

- Lab 6: The students used this lab to practice parallel I/O interface skills: a LCD unit was interfaced to the microcontroller. Students also learned skills related to the concept of interrupts. Although not used in the final mobile robots, the expectation was that the LCD display would eventually display the IR sensor results.

- Lab 7: The real-time features of the microcontroller and related programming skills were taught in this lab. The lab used two timing features which generated pulse-width modulated signals for motor speed control and also monitored the number of pulses generated to determine when speed changes were necessary. This lab used the Lab 5 program and real-time I/O hardware to actually control the two motors and move the mobile robot in a straight motion. The students also used the interrupt function of the microcontroller in this lab.

- Lab 8: This lab was an extension of Lab 7; software and hardware were modified to allow the robot to turn. Students were responsible for implementing both the software and hardware.

- Lab 9: This lab utilized the analog-to-digital converter of the 68HC11. Each student was given a sensor board which contained three IR emitter/detector pairs. The sensor pairs were used to detect walls as the robot approached them. Students used software from Lab 2 and added a software extension to incorporate actual sensor data.

- Lab 10: This final lab was used to put together the nine previous labs. The students used the navigational capabilities of the robot accomplished from Labs 7 and 8 and combined them with the sensing capabilities obtained from Lab 9. Both capabilities were then used to navigate through a specially designed maze. The objective of the lab was to incorporate various functions of the microcontroller with related programming skills to create a working mobile robot. To add some additional excitement and motivation to the final project, we conducted an in-house mobile robot maze navigation competition (see Figure 2).

**DISCUSSION**

In this section we present some overall course observations, made by those who designed and administered the course to the students, followed by student feedback.
A careful planning effort by multiple individuals before the first class meeting was the key factor in making the course successful. We had to design and construct simple but useful robot bodies; motors and sensors had to be selected, tested, purchased, and mounted on the robots; cables connecting sensor boards and motors to portable labs had to be made; mazes (4) had to be designed and constructed, etc. We were fortunate to have both two faculty members who were actually teaching the course (2 sections) and two other interested faculty members who were available to help out during lab hours. The availability of professional machinists who constructed the robot frames and the mazes was crucial.

Another key factor for the success of the course was our approach of laying out the road map for the course. We explained to the students the importance of course materials, how those materials would be used to accomplish each lab, and where each lab fits in the final mobile robot project. Having the “big picture” of the course seemed to enhance student learning, not to mention their willingness to learn. Since the success of the mobile robot project required the success of all previous labs, some students needed extra help. This meant the instructors had to be available and ready to support these students: we provided students who were falling behind with some
hardware design and program segments (sometimes an entire program) of previous labs. As previously mentioned, incomplete and/or unsuccessful labs suffered appropriate grading penalties.

The effort put into the course was worthwhile. The mobile robot project provided students opportunities to become creative while enjoying the learning experience. A programming course inherently provides this type of opportunity, but the mobile robot project provided additional motivation and opportunities, e.g., many novel navigational control schemes were developed. The integrated labs, as evidenced by the student responses, helped students to enjoy the course. And each lab, with a reachable goal, still allowed students to focus their efforts. The competition at the end was also well received by the students. They seemed to enjoy the challenge and had fun learning the material.

The experience also exposed students to the skills necessary to accomplish a large project. For most students, the course was their very first opportunity to work on a large project. The experience of reusing software and hardware, practicing top-down design skills, and learning skills for a real-life application was invaluable.

We believe the course was successful due, in large part, to the way the lessons and labs were structured toward keeping the final objectives clearly in focus. The students knew from the course outset that they would be programming a robot to explore a maze. The lessons led the students step-by-step and kept that objective fresh in their minds. They remained interested.

Student feedback was very positive. The student responses were generated by using an anonymous survey; the results supported the informal feedback we received. The survey questions were divided into two categories: questions related to the project and questions related to the quality of the labs.

The following four questions, related to the integrated project concept, were given. Students rated each question as strongly agree, agree, neutral, disagree, and strongly disagree.

1. Completing the ten labs required in this course significantly helped my understanding of the course material.

2. Working on labs as sub-parts of one large project (the mobile robot) helped me to see how various functions of the microcontroller can be used together.

3. Having one large project enabled me to see where the course was heading throughout the semester.

4. I would have preferred to have independent labs which only concentrated on one function of the microcontroller at a time. (i.e., no mobile robot).

The results are shown below.
The results show that 100% of the students either strongly agreed or agreed to question 1. Questions 2 and 3 addressed the value of one large lab and the students responded positively: over 90% of the students thought the labs provided integrated knowledge while 100% of the students strongly agreed or agreed that the mobile robot project provided a road map for the course. In contrast, when we asked whether students would prefer an independent lab series, the students responded with a resounding “NO” with over 87% of students disagreeing or strongly disagreeing with the statement in question 4.

The following six questions related to lab quality were also given to the students (again rated as strongly agree, agree, neutral, disagree, and strongly disagree).

5. The mobile robot maze navigation competition is an excellent idea to increase the level of intellectual curiosity among cadets.

6. The mobile robot labs worked well for me as motivational tools.

7. The portable lab unit was used substantially in my dorm room to complete the labs.

8. The help provided by EE382 instructors in support of my efforts to complete the labs was outstanding.

9. Providing lab solutions over the computer network for use in subsequent labs significantly helped me to be successful in the course.

10. I am satisfied with the equipment, lab facilities, and classrooms used in this course.
The responses to questions 5 and 6 showed that the course motivated and intrigued students positively: the competition helped to raise the students’ interests as shown by over 84% of students agreeing or strongly agreeing to question 5; the mobile robot labs also motivated students as shown by their responses to question 6 where about 70% of the students responded positively. A brief explanation is in order for the students’ response to question 9. The response shows about 40% of students responded positively (negative response is good). This result is because approximately 60% of the students performed all the labs on their own without resorting to solutions provided by the faculty.

CONCLUSION

In this paper we presented our experience in incorporating a large mobile robot project, in the form of a series of integrated labs, into a junior level electrical engineering microcomputer programming course at the United States Air Force Academy. We showed the advantages of offering such labs to students in terms of desired student learning and the general level of student interest. A mobile robot competition at the end of semester provided students an avenue to combine their engineering problem solving and creative skills. We presented observations made by both faculty and students which showed the merit of an integrated lab series in a computer programming course. Advantages of such labs include providing students with an integrated road map for the course, exercising the top-down approach to a large project, and enhancing the skills associated with the requirement to reuse software and hardware.

Bibliography

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