AC 2009-996: TEACHING MICROCONTROLLER APPLICATIONS USING LAPTOP COMPUTERS

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Teaching Microcontroller Applications Using Laptop Computers

Abstract

This paper presents an inexpensive technique of teaching an introductory microcontroller applications course to technology students in a laptop-based curriculum. The focus of the course is learning to apply microcontrollers in various control applications. Related topics covered in the course include assembly language programming and computer architecture. Students in the course are each equipped with a laptop computer. The microcontroller platform used in this course is the Microchip PICKit1 development board. This development board features 8- and 14-pin microcontrollers with a 35 word instruction set. This is an ideal platform because the devices have enough resources to develop realistic applications but are not so complex as to be intimidating to the students. The PICKit1 board has a USB interface and several I/O devices. A minor modification permits this development board to be used as a microcontroller programmer. The students begin by getting familiar with the devices on the development board. Then, more complex off-board control applications are developed using the PICKit1 as a programmer. The students use their laptops to develop microcontroller software and program devices. Since the PICKit1 development board is less expensive than most textbooks, students purchase their own boards. The development software is available at no charge from the manufacturer. In combination with a laptop computer, this low cost approach is very flexible and allows students to perform experiments in class and across campus without being tied to a microcontroller laboratory.

Introduction

An inexpensive technique of teaching microcontroller skills to technology students is presented in this paper. Typically microcontroller development courses are taught in a dedicated lab using development boards or systems linked to desktop computers running the appropriate development software. These development systems target a specific microcontroller family covered in the course. Limitations of this approach include the fixed number of workstation seats available, constraining students to a physical lab location, and limited lab availability.

In the 1999-2000 academic year Northern Michigan University began requiring all incoming freshmen to have laptop computers. To fulfill this requirement and enforce uniformity across the campus, students were provided machines by the university. The laptops were funded by a $300.00 USD fee charged each semester as part of tuition. All students were required to participate in this program. By the 2003-2004 academic year every student enrolled in the university had a laptop. The laptops in use were essentially identical in capabilities. They ran Microsoft Windows XP as the operating system and had a basic suite of applications installed on them by the university. One goal was to utilize these laptop computers to improve the student learning experience in a microcontroller applications course for technology students. A second goal was to improve the learning experience without significantly increasing the cost of course delivery and minimizing the per seat cost due to budget constraints.

Prior to 2004, the microcontroller applications course had been taught using the Microchip PIC family of 8-bit flash programmable microcontrollers. The lab consisted of desktop computers running the development software and connected to a device programmer. Students would use this environment to program their microcontrollers and then insert these programmed parts into a third party evaluation board to test their application. The limited number of lab stations equipped with programmers and evaluation boards coupled with the limited lab hours made it difficult to accommodate larger classes. Comments from student evaluations indicated that they were frustrated with the limited access to the equipment in order to complete lab assignments and projects.

Starting with the Fall, 2004 course offering, the Microchip PICKit1 development environment[1] was used as a laptop-based development platform for the microcontroller applications course. The chief advantages of this approach were the integrated portable nature of the development kit which worked well with a laptop environment and the very low cost of the kit, $27.00 USD with a university discount, well below the cost of a textbook. Another advantage was that this development kit permitted using the same family of 8-bit flash programmable microcontrollers as had been taught in prior years although the specific devices were different. Students downloaded datasheets for the target microcontroller used in the course and the development kit[2,3].

Microcontroller Development Environment

The Microchip PICKit1 Development Kit consists of an evaluation board, MPLAB software, and PICKit1 software[4]. This kit is capable of programming several different 8- and 14-pin microcontrollers. The complete kit is shown in Figure 1. The board connects to a

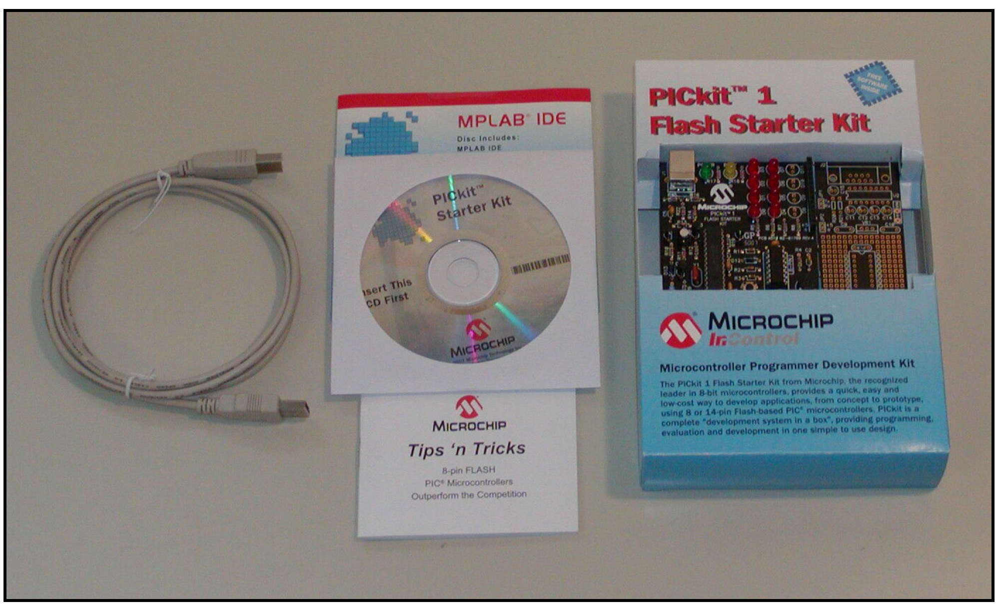

Figure 1. PICKit1 Development Kit

laptop via a USB port and requires no other connection. The board contains a device programmer, some simple devices connected to I/O pins, and a small prototyping area. There is also a header that can be used for PICKit1 daughter boards or other purposes. The stock board is shown in Figure 2. The software bundled with the kit includes the MPLAB IDE and the

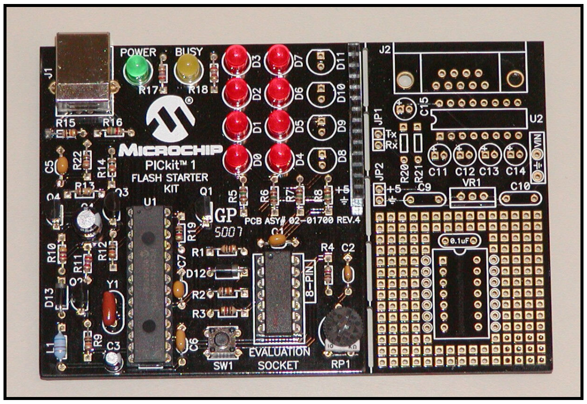

Figure 2. Stock PICKit1 Development Board

PICKit1 flash programmer software. The MPLAB IDE contains an assembler, debugger, and simulator for Microchip microcontrollers. The PICKit1 software permits programming devices supported by the PICKit1 board and also allows controlling power to the board.

The target microcontroller used in this course was the 14-pin 16F676 which offered enough I/O capabilities to do some interesting exercises without overwhelming students in their first exposure to embedded systems. The instruction set consists of 35 instructions which is very manageable for students in an introductory microcontroller course. The key capabilities of the 16F676 microcontroller are summarized in Table 1 below.

Table 1. PIC16F676 Microcontroller Key Characteristics	
Program Memory	1024 words
Data Memory (SRAM)	64 bytes
Data Memory (EEPROM)	128 bytes
Input/Output pins	12
10-bit A/D converter	8 channels
Comparators	1
Timers	2 (1 16-bit, 1 8-bit)
Instruction Set	35
Maximum Clock Speed	20 MHz
Internal Clock Oscillator	4 MHz

In order to make the board more useful as a device programmer, students modified their boards in the first session to add a zero insertion force (ZIF) socket in the prototyping area. This modification permitted programming and removing devices more easily. A modified board is shown in Figure 3. A complete setup of the laptop, development board and software is shown in Figure 4.

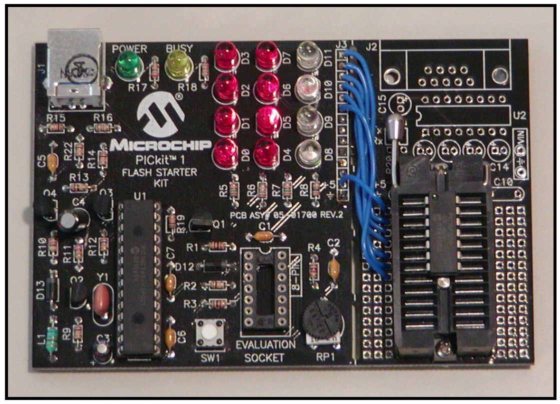

Figure 3. Modified PICKit1 Development Board

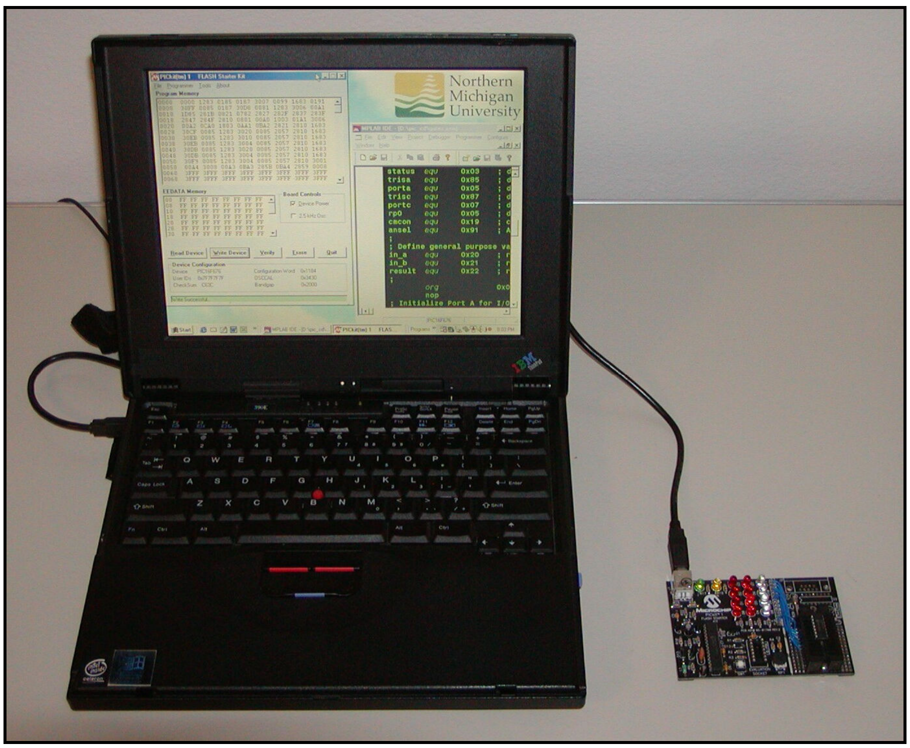

Figure 4. Complete Microcontroller Lab Environment

Course Exercises

The technology students enrolling in this course had a one semester background in a higher level programming language and digital logic. The students had no prior experience with microcontrollers, embedded systems, assembly language, interfacing or computer architecture. The goal of this course was to give them an understanding of these topics from a technologist's perspective. The course began with an explanation of microcontrollers and embedded systems development. A discussion of the 16F676 features and architecture followed. The programming process, assembly language programming, and use of the development tools were also discussed. The students performed a sequence of assignments to learn about different features of the microcontroller and the instruction set. These assignments are listed in Table 2 below.

Table 2. Microcontroller Applications Student Exercises		
Assignment Description	Topics	PICKit1 only
Switch controlled LED	Familiarity with development tools	Yes
PLD Simulator	Use of logical instructions	Yes
Strobed LED Flasher	Decisions, looping, instruction timing	Yes
LED Flasher	Timer, polling	Yes
Electronic Dice Project	Timer, polling, instruction set	Yes
Binary to hex converter	Indirect addressing	No
LED flasher	Timer, interrupts	Yes
A/D converter	A/D conversion, polling, interrupts	Yes
7 Segment LED driver	Indirect addressing	No
Digital thermometer	Integrates all previous work	No
Development Project Examples	Process Control Timer System	No
	Bicycle RPM and Cadence Monitor	No
	Electric Vehicle Battery Status Monitor	No
	Portable Alphanumeric LCD Thermometer	No

A majority of the assignments utilized only the PICKit1 board so the students had freedom to work on them in class or at home. The last few assignments required the use of a protoboard with a USB connector to power the circuit from the laptop without requiring additional hardware. The course culminated in a longer individual development project using the 16F676. This project was intended to integrate key concepts from the course and was assigned during the last month. Examples of assigned development projects are listed in the bottom portion of Table 2.

Student Feedback

One objective of this approach to teaching microcontroller applications was to improve the student learning experience. The experiences of students can be evaluated through a number of techniques such as course grades, student evaluations, written comments, and anecdotal evidence. This course was offered from 2001 to 2004. The 2004 offering used the PICKit1 development kit. Course grade information and evaluation data are summarized in Table 3.

Table 3. Student Assessment and Feedback				
Metric	2001	2002	2003	2004
Average Final Grade	82% (B-)	80% (B-)	83% (B-)	88% (B+)
Average Course Evaluation Score	87.4%	87.0%	84.6%	85.6%
Course Evaluation Written Comments				
Lab Availability Negative Comments	12.5%	13.3%	28.6%	0.0%
Lab Availability Positive Comments	0.0%	0.0%	0.0%	0.0%
PICKit1 Use Positive Comments	N/A	N/A	N/A	83.3%
PICKit1 Use Negative Comments	N/A	N/A	N/A	0.0%

The average course grade for the class as a whole increased from a B- to a B+. The overall numerical score on the course evaluation did not change significantly. Written course evaluation comments indicated that students did not feel constrained by limited access to lab facilities as had been the case in the years prior to 2004. Written comments on the student evaluations indicated that a majority of the students in the 2004 class liked the freedom and flexibility of using the PICKit1.

Cost

Another objective of this approach was to reduce the per seat cost of offering a microcontroller applications course. The per seat costs of the 2003 and 2004 course offerings are summarized in Table 4.

Table 4. Microcontroller Applications Per Seat Costs

2003 Delivery	Department Cost*	Student Cost
Desktop PC running Windows XP	$500.00	
Microchip PICStart Plus Programmer	$70.00	
PIC16Fxx Series Demo Board	$85.00	
Microcontroller Devices	$10.00	
2003 Per Seat Total	$665.00	
2004 Delivery	Department Cost*	Student Cost
Laptop PC running Windows XP		$300.00 (Required semester fee)
Microchip PICKit1 Development Kit		$27.00
Hardware to add ZIF socket	$10.00	
Microcontroller Devices	$10.00	
Solderless Protoboard with USB Connector	$10.00	
2004 Per Seat Total	$30.00	$327.00
*Straight line depreciation over 3 year equipment lifespan		

The total per seat cost in 2003 was $665.00 using a straight-line depreciation method over a three year equipment lifespan. In 2004, using the PICkit1 boards, the total per seat cost dropped to $357.00 when the departmental and student costs are combined. This is a significant reduction in per seat cost from the prior year. The data in Table 4 shows that the cost burden is largely being moved from the department to the student and consists chiefly of the laptop fee. Given that the students are required by the university to have a laptop, the PICKit1 environment is an effective way to utilize that laptop. Since students would be using the laptops in other courses taken during the semester, the $300.00 cost would be spread across those other courses as well. Thus, the $300.00 laptop fee cited in Table 4 represents a worst case scenario.

Conclusion

Two goals of this project were to utilize laptops already required of students to improve their learning experience in a microcontroller applications course and to reduce the per seat course delivery cost. Using laptops in conjunction with the Microchip PICKit1 did improve the student learning experience as reflected in the course grade and course evaluation written comments. Per seat costs of this approach were approximately half the cost of maintaining a dedicated microcontroller lab. Written and verbal comments from students using the PICKit1 development kit indicated that they enjoyed having the freedom to work on their microcontroller projects at any time. Follow up anecdotal evidence also indicated that the flexibility and portability of the development environment was a significant factor. Many of the students taking the course in 2004 continued to use the PICKit1 environment to develop microcontroller solutions for other academic and non-academic applications. This willingness to apply microcontrollers outside of a specific microcontroller class had not been common in students taking the course during the 2001 to 2003 academic years which had required access to a dedicated lab to develop microcontroller projects.

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