Increasing Student Interest Through Hardware Ownership

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Abstract

With the significant drop in cost of embedded microcontrollers,[1, 3] there now exists an opportunity to give every student a trainer that they can take home to work on and can keep at the end of the semester. At Vermont Technical College, one of the courses has been modified to include a Microchip PIC16F877 based trainer board. The trainer board comes in kit form (a PCB and components) and the students assemble the board and then use it in several labs and a small project at the end of the semester. This paper details the trainer board itself and the benefits it has brought to VTC and its students.

Introduction

Vermont Technical College has previously used lab based microcontroller boards in several of its courses. These have included ISA bus extenders, 68HC11/12 trainers, and 386 trainers. All of these trainers have been used and stored in the labs and are only available to students during lab times and during the evenings when lab monitors are present. Starting three years ago, we introduced a PIC16F877 based microcontroller trainer board kit (Figure 1) that the students assemble, use in lab, and take home with them to keep. The board is simple enough to allow most troubleshooting to be performed with a volt meter, yet powerful enough to develop applications that use pushbuttons, LEDs, LCD interfacing, timers, RS-232, PWM, interrupts, EEPROM, and A/D conversion.

Over the last three years, we have noticed some distinct differences between students using their own trainer boards and the VTC owned trainers kept in the labs. Students have shown much more enthusiasm in getting labs to work on their trainers, and the equipment is better maintained and repaired immediately upon failure. Because students have to fix their own boards (with assistance from faculty) when they break them, the students are less likely to accidentally short outputs or overvoltage inputs.

Figure1: The trainer board kit

This paper describes the trainer board in detail as well as applications and student reactions.

The Trainer

The trainer was designed by William McGrath (another faculty member at VTC) and myself for the ELT-2040 *Computer Systems, Components and Interfaces* course. It is based on Microchip's PIC16F877 processor. This low cost 8-bit microcontroller that has flash memory for student programs as well as hosting a multitude of peripherals on-chip[4]. The trainer board adds a voltage regulator, four LEDs, two pushbuttons, a four-line LCD with backlight control, an RS-232 interface, an analog temperature sensor, as well as a header for additional expansion. The processor is in-circuit programmable[5] with free software for Windows and Linux. The assembled microcontroller trainer system is small enough for the students to store it in an empty VHS case for transport between dorm and lab room.

To begin with, the students are given the PCB and a schematic (Revision A). They are charged with following the traces on the 2-layer PCB and determining the differences between the PCB layout and the schematic (see figures 2 and 3.) This is given as a homework assignment. There are quite a few differences, and the students are expected to find most of them. This also gets the students familiar with the layout of the board.

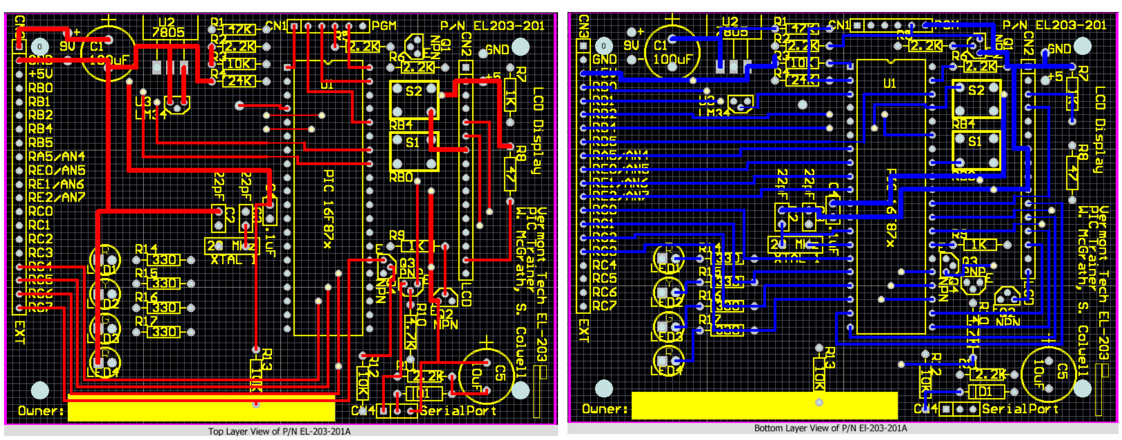

Figure 2: Board Layout (top and bottom layers)

Once the differences have been located, the students are given a new schematic (Revision C). This schematic details the final hardware for the board the students have been given. Some of the previous differences the students found have been corrected in this schematic while those that are left will need to be fixed by the students during assembly of their trainers. While we considered correcting the last few errors on the board layout, the experience of having the students cut a trace and add a jumper has since been seen as a beneficial part of the learning experience and so those errors have been left in the PCB.

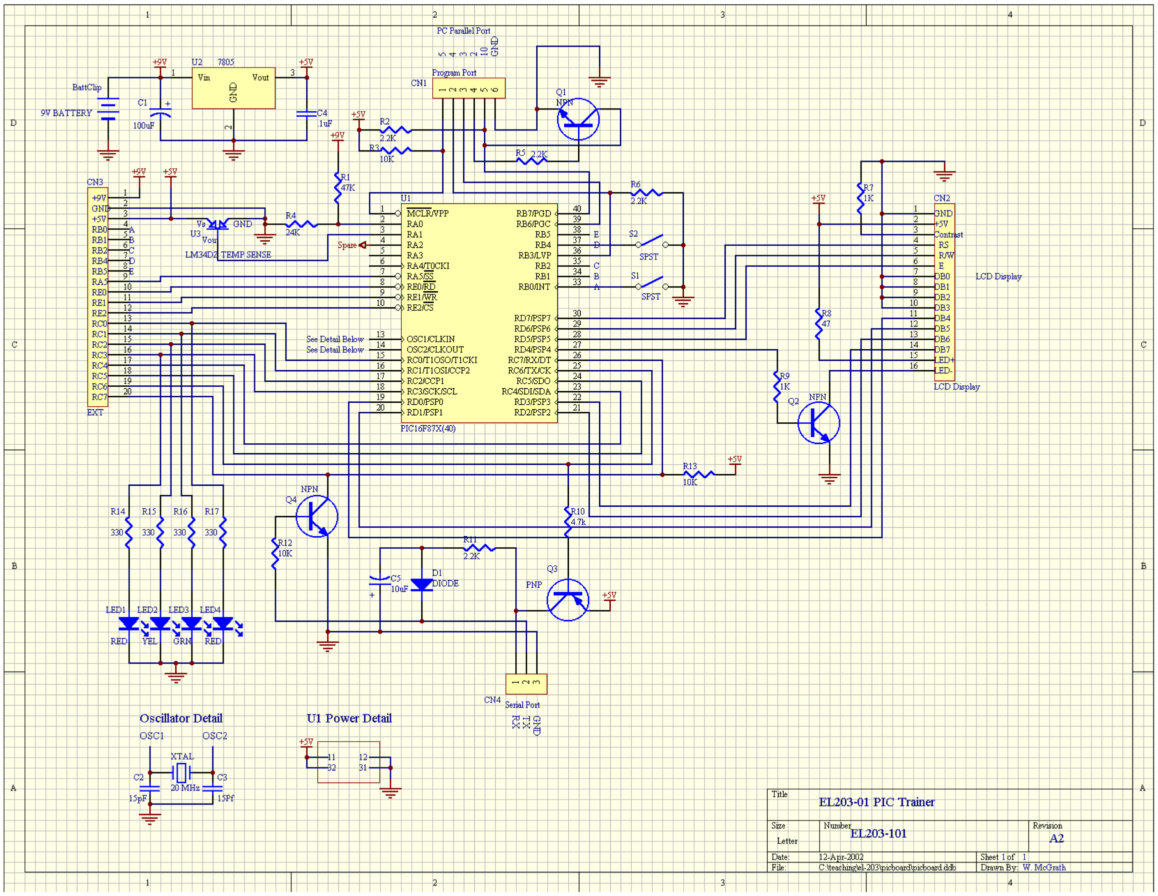

Figure 3: Trainer Board Schematic (Revision A)

The students are then given two lab periods to assemble their trainers. This gives the students experience soldering. In addition, the students have to alter the board to fix the aforementioned errors in the board itself as well as to add a few extra components (capacitors and a resistor) that are not in the board layout at all. These are added by tack-soldering them to the back of the board.

Once the students have fully assembled their boards, they are given a test program to download to their trainer to verify its functionality. For the next two to three weeks, the students are given prescribed labs to perform with their trainers. These labs get the students to use the pushbuttons, the PWM module, the A/D module, the EEPROM, and the LCD. The remainder of the semester (about four weeks) the students are allowed to develop their own projects that must meet some basic criteria. While the entire experience with the PIC microcontroller was exciting for the students, this phase brought out the most enthusiasm amongst the students. Students who had shown little interest in the labs prior to working with the PIC showed great excitement and motivation when allowed to create their own project. Having the seniors show their projects to other underclassmen also seems to create more interest in the circuits and micro classes as these students get to see actual applications of the basics they are learning[2].

"Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition

Use

The students download and install MPLAB from Microchip's web site (http://www.microchip.com). This software includes an IDE, an assembler, and a simulator and is a fully-functional free download. The software for the boards is then written in Microchip assembly and is assembled into hex files. The students can simulate their software within the IDE and can set breakpoints, watch variables, and use a stopwatch feature to time their routines.

To program their boards, the students connect a programming cable (part of the kit) from the parallel port of the PC to their boards. A free program named IC-Prog is used to download the software to the board (http://www.ic-prog.com). When the programming cable is unplugged, the new software begins to run immediately.

For students that use Linux, a free assembler named GPASM is available and is compatible with Microchip assembly syntax (http://gputils.sourceforge.net). This software will assemble the student's programs into hex files which can then be programmed with PicPrg (http://www.finitesite.com/d3jsys).

Example Assignments

Many of the assignments given to the students focus on a particular hardware aspect of the trainer board. In this way, the students can learn about the board one module at a time and can later use several components simultaneously when they get to do their own projects. The students are given some code libraries that contain functions for dealing with the LCD so they can print text and numbers to it, functions for dealing with the A/D converter, and several delay functions ranging from 1ms to 1s. In class, the students are shown how to initialize and use the various peripherals built into the PIC microcontroller, although the actual logic of the programs assigned is left for them to complete. The following assignments are typical of what the average student is asked to do (usually due in two classes to allow class time for questions.) These assignments typically take the students 2-3 hours outside of class.

The students are asked to turn the red LED on and the green LED off when one button is pressed, and vice versa when the other button is pressed. This gets them comfortable doing bit operations and working with the switches and the LEDs.

The students are asked to place a star (the asterisk) on the first line of the LCD. One button should move the star to the right while the other moves it left. The star should be contained on the first line and should stop when it reaches either edge. The buttons should be debounced in software so the star only moves once with each button press. This gets the students comfortable moving around on the LCD screen and has several unique solutions.

The green LED on the board happens to be connected to one of the PWM outputs. The students are asked to use the PWM module to control the brightness of the LED. There should be 10 steps (11 total levels) to the brightness, and one button should be used to make the LED brighter while the other makes it dimmer. The brightness should stop at its maximum and minimum levels. This gets the students familiar with the PWM module as well as reinforcing button handling techniques and dealing with limits in software.

The students are asked to display a number on the screen. They must make one button increment the number and the other decrement it. Their software must allow the user to hold down the button to change the number more rapidly. The students must save the number in EEPROM each time a new value has been selected, and have the unit power back up with that number if the power is disconnected/reconnected. This gets the students used to dealing with EEPROM as well as introducing some more advanced button handling techniques.

Issues

Most of the major issues occur during the assembly of the boards. The assembly instructions are highly detailed and explicit in the assembly and testing of the board, however not all students actually follow the instructions. The most common mistake is to incorrectly place the pin header on the left side of the board (where many of the PICs inputs and outputs are connected for expansion). The instructions clearly state to install the pins so they stick down underneath the board so that it can be easily plugged into a breadboard for prototyping additional circuits. Several students in past years have installed this on the top side of the board with all of the other components, and it is quite difficult to remove and reinstall once soldered into place.

Another issue to watch for is the installation of the electrolytic capacitors. If they are installed backwards or excessive voltage is applied, it is possible that they could explode. Before the assembly of the boards the students are warned of this fact and it has not been an issue.

On a few occasions, the students have incorrectly applied power to their boards. This includes reversing the polarity of the power supply and applying power to output of the voltage regulator (one of the pins on the side of the board has +5 out from the voltage regulator for use in external circuits). If these situations are caught quickly and resolved, there is usually no damage to the boards. If the boards do not function after correcting the problem, then the crystal should be checked/replaced followed by the PIC if it still doesn't work. So far, this procedure has resolved all of the issues with improperly applied power. The students do all of the testing and replacing of parts when needed under the guidance of the lab instructor, and these students generally take much better care of their boards after having to fix them once.

These boards are programmed through the parallel port. They work with 5V parallel ports as well as with 3.3V parallel ports. A couple of students have had issues with some laptop ports that do not put out a full 3.3V, however most of the laptops tested have worked fine.

Outcomes

The PIC microcontroller has been used for three academic years now, and the first students to use it are currently seniors in the Bachelors program in Computer Engineering Technology. In their senior projects class, the students all developed a project with similar requirements. Briefly, the requirements were to develop an external hardware/software based device for a PC that allows the user to select from two pieces of information on the Internet that are then displayed on the external device in real time. Interestingly, all five groups chose to use their PIC trainer board that they built two years earlier as sophomores. The students had other options available to them, such as a Motorola 68HC11 trainer, a 68HC12 trainer, an Altera UP-1 CPLD development board, or a parallel port based solution. To highlight some of the projects these students developed, one group's PIC microcontroller allowed the user to select from two nearby movie theaters and displayed the movies currently showing at the selected theater; another group chose to develop a system that either looks up which classes are canceled that day or retrieves the local weather forecast.

Having the students own the trainer board is a key component to facilitate learning. John Murphy, P.E., another instructor at Vermont Technical College, also uses a student-built microcontroller -- a Motorola based 68HC08 based trainer -- in his classes. He noted that when students owned the boards they took much better care of them. From previous experience, when five students opted to take the boards on loan instead of purchasing them, all five boards were returned in non-working condition. Those students got frustrated with the hardware and lost interest in the assignments. On the other hand, the students who owned the trainers took responsibility when they accidentally destroyed components on their trainers and immediately fixed the trainer or sought help if they couldn't fix it themselves.

Conclusion

The faculty at Vermont Technical College have noticed a great increase in student interest and enthusiasm by allowing the students to take the hardware home with them and keep it at the end of the semester. Students take better care of the equipment and are more likely to complete a challenging project if they know that they get to keep the result when they are done. This improvement has been so dramatic at VTC that purchasing the trainer kit is now mandatory for the course that uses the PIC based trainer. The cost of the complete kit is around $40.00.

Keeping the design of the trainer relatively simple appears to be important to the students as they seem to feel more comfortable when they can understand the entire system after working with it for just a short while. Having the students trace out the boards and assemble the kits helps familiarize them with the workings of the trainer. The current trainer design seems to have enough peripherals to keep the students interested while not being so complex that the students get lost trying to figure out how to use each of the peripherals.

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Biography

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