A Microprocessor Design Course
That Integrates Hardware, Software, and Team Research

Marcus O. Durham, PhD   Matthew Olson, BS
The University of Tulsa

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Abstract

The Electrical Engineering microprocessor design course, like most design curriculum, allows students to develop practical engineering skills. At the University of Tulsa, we have augmented this to simulate a custom design house[1].

The students build 11 computer projects during the fall semester of the senior year. The projects begin with basic input / output, and then proceed through timers, serial communication to a PC, seven-segment displays, keyboards, liquid crystal displays, and analog conversion.

These are performance-based projects. The mission is discussed in a lecture. The functional criteria are specified. Then it is up to the student to determine and purchase the hardware required. After that, the hardware must be integrated with the software. Each student must construct his own prototype on his schedule. The professor and assistants are available on a preset schedule to provide aid and to check the performance.

I. Introduction

Like the real world, the students can obtain information from any source, including other students in the class. The only requirement is the sources and other student names are listed on the report. This encourages great camaraderie and fantastic design solutions.

After the first few projects, a custom designed printed circuit board is available. This board contains the fundamental components of the computer system, with space to develop other components.

A report is prepared for each project. The report must be adequate for someone to build the equivalent device. This includes an executive summary, a table with time required for planning, design, construction, troubleshooting, and report preparation. Another table lists the parts and cost of each component. Schematic drawings and software code are also included with the detailed report and recommendations for improvement. All reports, drawings, and schematics must be computer generated.

On the first day of class we have a discussion with the students. The professor asks what have you heard about the class. If they are not aware of the extensive work involved, there is an explanation of the time expectations. Then there is a promise that goes with the class. If you complete all the projects, you will be able to build anything you desire with a computer. Although that is a rather strong statement with a strong commitment, this class has proven to be the most popular elective in the Department.

The Professor and a student are writing the paper. The student was a senior who took the class. Then he designed the printed circuit board. Now he is a graduate teaching assistant in the project component of the class.

The entire course curriculum is placed on the web. Project status is also posted on the web[2]. Email is used for communications outside of scheduled times. This makes the class very interactive while providing tremendous flexibility to everyone's schedule. Teaching evaluations have been extremely positive about the web-based approach. Comments have suggested other classes adopt the technique.

II. Projects

There are 11 projects through out the semester. Only one exam is given about four weeks into the semester. This is to assure that the students are doing the projects themselves, rather than someone else providing the work. The major portion of the grade is based on project development. These projects are listed with the objective of each task described.

1. Metronome

   The simplest usable information that can be gained from a computer is turning on a single lamp or indicator. A light emitting diode (LED) is flashed at a rate based on the characters in the developer's name. The objective is to implement output based on nothing other than counting the number of instructions executed and moving the data to an on-board address. This task is performed with machine code.

2. T'bird taillight

   After digital output is established, discrete inputs are the next requirement for a computer. A sequence of LED's are flashed reminiscent of early Thunderbird automobiles. Two toggle switch combinations can select right, left, brake, or idle. The project adds input, logic, and decision-making. Assembly language can now be used for this and succeeding projects.

3. Timer / Counter

   Use of internal registers and internal memory increases the power of the hardware. The number of events is counted and an LED is illuminated after a preset value. The process adds use of internal registers. The events may be elapsed time or an external switch.

4. Serial communications

   Communications between different computers is critical for exchange of information. Interchange is established between the microcontroller and a PC. Serial communications protocol and signal levels are implemented on both computers using RS232 standards. This allows connection to any serial device. It also allows a convenient trouble-shooting tool.

5. Board development

   A custom designed printed circuit board is available to implement the microcontroller basic logic. This board has the architecture for a complete computer with capabilities for implementing other external circuits. The board is discussed in detail below. The student must obtain parts, build, test, and demonstrate the operation of his board.

6. Memory mapped
   The number of devices that can be added to the microcontroller is expanded using memory mapped input / output (IO). This type interface can be used with any computer. The T'bird taillight project is moved from input / output ports to memory output.

7. Seven segment display
   Display of information is critical to any computer system. While LEDs provide discrete information, most devices such as microwaves and thermometers use a seven-segment display to provide numbers.

8. Keyboard
   A keypad is the fundamental data input platform for virtually every controller. Because of the large number of keys for a restricted number of inputs, it is necessary to develop matrix techniques. Tables are then used for rapid conversion of the information to different formats.

9. LCD
   For display of text data on a control system, the liquid crystal display (LCD) is the unit of choice. It is relatively inexpensive for the quantity of data. However, the device requires extensive coding to make it compatible and user friendly.

10. SPI communications
    A large number of external interfaces are available for microcontrollers. Because of the small size required by most applications, these often use serial peripheral interface (SPI) protocol. This involves hanging multiple devices on two lines. The device is selected by a third line. Then the address is sent, followed by the data communication. Common devices include analog to digital converters and static memory units.

11. Analog input
    The whole world is an analog stage. Digital only plays bit parts. Therefore, investigation of real world events requires interface through analog inputs. A variable voltage is read with the results displayed on a local display as well as on the serial communications.

The class and board are built around the most used core controller, the 8051. The processor was originally developed by Intel in 1979[3, 4]. However, it has been enhanced and is now made by numerous vendors[5]. The microcontroller was picked because of its unique architecture. It has the Harvard architecture of split memory. This is a shared family trait with the larger Pentium series. In addition, it has many instructions and programming features that can correspond to the Princeton architecture.

Since the machine can be directly implemented as a controller for myriad tasks, it is usually the device of choice for most integrated control systems[6]. There are arguably more implementations of the 8051 in its various forms than of the Pentium in all the personal computers. In fact, it is the controller within many devices such as keyboards, disk drives, and infrared remotes. This makes it a highly desirable tool for design engineers.

III. Board Design

This is the third iteration of the board since the class was first developed 15 years ago[7]. Although the same core microcontroller is used, it has been necessary to continually make changes to keep up with the technology advancements so prolific in the computer industry.

Recent developments with memory technology have brought about the biggest changes to microcontrollers since their introduction in the 1970's. Today with the implementation of flash memory and the continued decline in cost of electrically erasable programmable read only memory (EEPROM), many microcontroller chips are readily available which have on-board memory. These can be programmed while the chip is installed in the circuit. Gone are the days of being the tethered to a chip burner for loading software onto the computer. These integrations have allowed a single chip installation that contains all features needed in a modern controller.

The diverse range of projects and applications of this board require it to become a multifunctional platform with two to three uses for each of the IO ports on the controller. Its main features are its ability to interface into almost any project. With the latches that are installed on-board, the IO ports can be used for many different applications. The platform also has an area dedicated to prototyping so that the developers own circuit can be added. Moreover, the printed circuit board has a built-in power jack and regulator so that it can take power from may different sources.

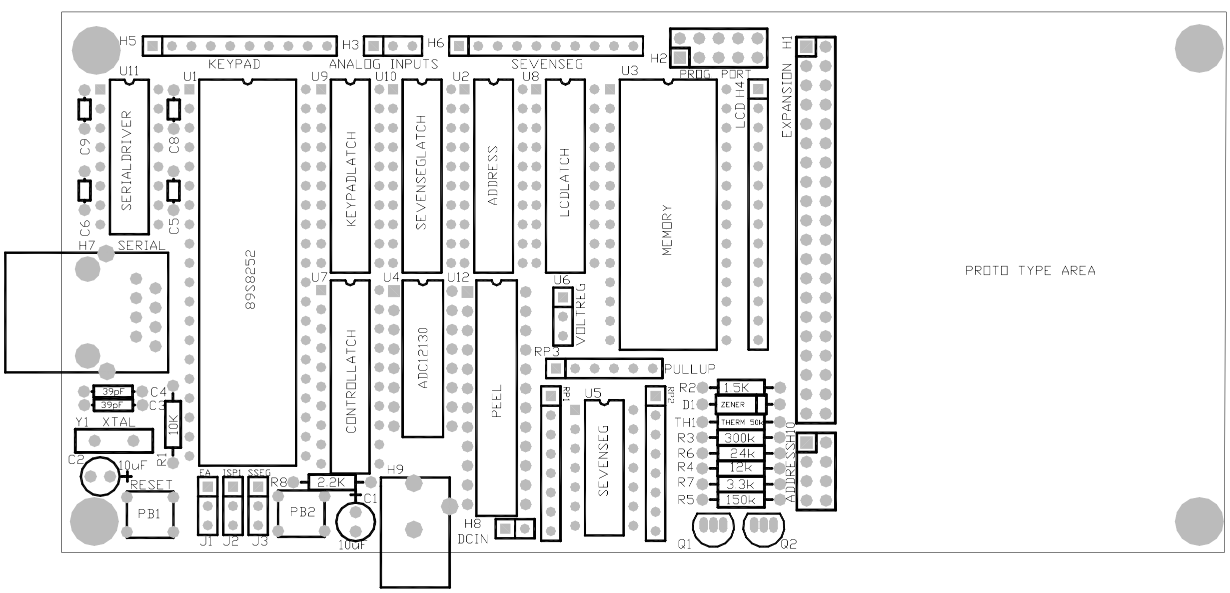

Figure 1: Layout of Printed Circuit Card

The board was designed to support the following features:

- 16 digit key pad
- liquid crystal display
- 3 seven segment displays
- 2 analog to digital converter channels
- memory mapped input / output (MMIO)
- serial communications (RS 232)
- serial peripheral interface (SPI) communications
- optional external memory eprom or sram
- 40 X 40 prototype area
- access to all port lines for adding custom circuits

IV. 7-Step Pattern

A consistent process is used in the development of any project. A seven-step pattern has been developed that works for software, hardware, and all other technical procedures. This is a universal model for engineering projects.

1. Entry
   The point where the procedure starts arises from a reset or from a decision.

2. Initialize
   A sequence of events or conditions are involved in the planning and set-up.

3. Input
   The loop first must gather data from other sources.

4. Process
   The core of the loop is manipulation of the data until a final value is obtained.

5. Output
   The defined results are displayed or provide input to another procedure.

6. Limit
   A test or decision is performed to determine if the loop is completed. The test may occur at three different places.
   a. The test may be implemented before input if there is a predefined loop range.
   b. A decision is made based on the input.
   c. An end is defined to do while some condition exists.

7. Exit
   The point to leave the project causes transfer to another procedure or task.

V. Observations and Outcomes

Numerous skills are developed in the process of the class. Planning and scheduling of tasks is paramount since so many projects are designed in such a short time. Purchasing and requisitioning of parts is critical to get the job finished on schedule. Research and troubleshooting are involved in obtaining solutions to design and construction problems. Weekly reports and record keeping are made on each project to provide information to the supervisor and to prepare for the next project implementation.

What is the one reason that most students enter engineering? Is it not to design and build things? The tasks are very intense, but the course allows the students to accomplish that primary motivating factor. Although it is very challenging in time and effort, the course continues to be the most popular elective in the department. That illustrates once again that students are willing to put forth very substantial effort, if they can see some reason and tangible results.

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MARCUS O. DURHAM

Marcus O. Durham is a Professor of Electrical Engineering at the University of Tulsa. He is also Principal Engineer for THEWAY Corp. and is President of Advanced Business Technology, Inc., an entrepreneurial business firm in the emerging e-Commerce arena. He is a registered Professional Engineer, a state licensed electrical contractor, a FCC licensed radiotelephone engineer, and a commercial pilot. Professional recognition includes Fellow of the Institute of Electrical and Electronic Engineers, Diplomate of American College of Forensic Examiners, and the IEEE Richard Harold Kaufmann Medal. He is acclaimed in Who’s Who of American Teachers (multiple editions), National Registry of Who's Who, Who’s Who of the PCIC/IEEE, Who’s Who in Executives and Professionals, Who’s Who Registry of Business Leaders, Congressional Businessman of the Year, and Presidential Committee Medal of Honor. He received the B.S. in electrical engineering from Louisiana Tech University, M.E. in engineering systems from University of Tulsa; and the Ph.D. in electrical engineering from Oklahoma State University.

MATTHEW OLSON

Matthew Olson is a graduate student and Teaching Assistant in Electrical Engineering at the University of Tulsa. He is a registered engineer in training. Leadership roles include team leader for Hurricane Motor Works Hybrid Electric Car Project, which was the winner of the Tour DeSol in 1999 and 2002. He is electrical team leader for University of Tulsa Gr.A.I.N.S. project which is working on building a granular physics project for the space shuttle. He is a member of the Rotary Youth Leadership Awards team held at Heart of the Hills camp. Honors include being voted top ten Freshman in 1999 at the University of Tulsa. He is an Eagle Scout and Vigil Honor member of the Order of the Arrow. He holds a State FFA degree in Oklahoma, and is a member of the Craig County 4-H Hall of Fame. He won best design for Senior Design Projects during fall semester of 2002 at the University of Tulsa.