Micro-Controllers in the Biological and Agricultural Engineering Curriculum at The University of Georgia

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Abstract

This paper is to report on a NSF sponsored project aimed at implementing a new pedagogical approach for teaching embedded systems to engineering students who do not necessarily have an electrical/electronics background. In particular, we will present two microcontroller courses developed at the University of Georgia for Biological and Agricultural Engineering students. Educational objectives, laboratory hardware and software and the set of experiments used will be described in this paper.

Introduction

Microprocessor courses have typically been taught within electrical engineering departments with an emphasis on computer architecture and software development. Recently, a shift is being made from teaching microprocessor architecture and the design of software to the use of microcontrollers in solving monitoring and control problems [1]. Several NSF funded investigators have explored and demonstrated the potential of teaching microprocessor-based design courses with an emphasis on mechatronic systems. Of particular interest are the courses developed in Stanford, Iowa State, and Berkeley [2,3].

We are aware of few engineering departments that are neither electrical nor mechanical, which offer microcontroller courses in their curricula. At the industry level, applications of monitoring and control fall in all engineering areas and are not restricted to mechanical or electrical systems. MCs are used for stand-alone applications such as microwave ovens and cameras, but in the industrial world, they are used as part of larger systems. Within these larger systems, MCs are used for low-level control functions such as control and compensation for a complex instrument, feedback control of one or a small number of loops. Developing expertise in MCs is crucial for biological and agricultural engineers since several instruments and processes in their fields are becoming increasingly complex with multiple MCs embedded in them.

In this paper, we describe our approach for teaching microcontrollers and embedded systems to Junior and Senior Biological and Agricultural Engineering students at the University of Georgia. In particular, we will address the two courses developed for this purpose and the associated laboratory hardware and software as well as the set of experiments used to reach our educational objectives. The courses also serve as electives for computer science students and they also fulfill requirements for a dual computer science/engineering certificate. Note that the rationale behind developing these courses, the history of course development and the educational objectives have been discussed in more detail in a previous paper[4]. In this paper we will focus on implementation and the developed set of experiments. Some of the discussion in the previous paper will occasionally be included for completeness sake.

Background and Educational Objectives

In the Department of Biological and Agricultural Engineering at The University of Georgia, we have a unique engineering student body. Our department offers the only engineering degrees at the University. We offer a bachelor's degree in biological engineering and another in agricultural engineering, which has evolved over the years from a traditional agricultural engineering degree to a "general" engineering degree. Students must select an emphasis in one of five areas: electrical and electronic systems, mechanical systems, structural systems, processing, and natural resource management. Therefore, in most of our classes, we deal with students with various backgrounds. This creates an interesting interdisciplinary environment.

In our electrical circuits, electronics, electrical motors, and sensors courses, we teach students the basics of how electrical, electronic, and electromechanical systems work. Through the microcontroller courses students get the opportunity to tie together the concepts they learned in these courses and learn how electrical, electronic, and electromechanical devices could be integrated with the microcontroller into a system that could solve important industrial problems.

Our Introductory Microcontroller Course

This course was restructured to place less emphasis on the microcontroller (Motorola 68HC11) architecture and software and more on its use in simple monitoring and control applications. Laboratory experience is introduced through the following exercises:

Getting acquainted with the assembly development environment and the monitor program BUFFALO

This lab takes the form of a tutorial which gets the students familiarized with the microcontroller development environment in the lab. Students are first acquainted with the hardware development system which consists of an evaluation board (EVB) developed by Motorola and a "target" board developed by a small company. The target board consists of various simple applications such as switches, beepers, and LED banks. Then students become familiar with the development software on the PC which is provided by Motorola (IASM). This software package is an editor, compiler, and communication package all in one. Students learn how to use the software to develop and assemble their programs. They also learn how to establish communication between the PC and the EVB board and download they executable code onto the chip. In doing so, students also learn the different commands of the monitor program BUFFALO used to debug and execute their programs.

Getting acquainted with the HC11 simulator

In this lab, students get familiar with the HC11 simulator also provided by Motorola (AVSTM). This software package is important for students to learn since it is an excellent debugging tool and it is also an excellent way of visualizing the inside of the chip.

Reading from and Writing to the Input/Output Ports

In this lab exercise, students experiment with the various input and output digital ports of the HC11 by reading switches and sequencing light emitting diodes (LEDs) on the target board.

Monitor Program Utility Subroutines

In this lab students become familiar with a range of utility subroutines provided by the monitor program and learn how to incorporate them in their own programs to accomplish various tasks. For instance they use subroutines for inputting data through the keyboard and outputting data to the monitor.

Interfacing a Keypad

The keypad is one of the most common input devices for user/system interfaces. Typically, these devices contain an array of keys each of which actuates a normally open switch. With appropriate interface hardware and software, the contact closure of any one of these switches can be detected by a microcontroller to determine that the key is being pressed. In this lab, students develop a program and build the hardware interface for interfacing a four-column by four-row alpha-numeric matrix connected keypad to the HC11 using program driven polling. Students develop modular and complex programming skills and improve their hardware and software debugging skills in this lab.

Interfacing an LCD Display

In this lab, students interface a Varitronix 20x4 LCD module to the HC11. The LCD has an on-board HD44780 Hitachi microcontroller. Students learn how to interface the HC11 with another microcontroller embedded in another device.

A/D Conversion and Temperature Measurement

In this lab, students learn how to use the microcontroller for data acquisition. In particular, they monitor the temperature of a water bath using the HC11. Students learn how to program the on-board A/D converter and they get the opportunity to build the necessary signal conditioning circuitry for interfacing the temperature sensor (AD590) with the microcontroller.

Our Advanced Microcontroller Course

The introductory microcontroller course provides students with an excellent basis for using microcontrollers. The next step is to provide students with the opportunity to integrate the knowledge and skills they acquired in this class into a real world project. Moreover, certain advanced features of the microcontroller are difficult to teach with simple independent experiments and need to be taught within the context of a broader real-world application. Examples of such advanced features include timer and interrupt capabilities of the MC.

The most important feature of our advanced microcontroller course is that it is built around actual and important engineering monitoring and control problems. This implies that at the beginning of the term, a problem is presented and its relevance to industry is illustrated with a few examples. Focus is then placed on introducing the MC in a way that highlights its different functions such as input/output, timing system, and interrupts. After students become familiar with what the MC has to offer as a design tool, a solution strategy to the monitoring and control problem at hand is developed with the different functions of the MC as building blocks. The most relevant aspects of the solution are broken down into smaller tasks and assigned as laboratory exercises. The rest of the course is spent developing the necessary skills to solve these tasks using the MC while keeping focus on the ultimate goal of solving the overall problem.

Description of the Experiments

DC Motor Speed Measurement and Control

The objective of this experiment is to control the speed of a small DC motor using the Motorola 68HC11 microcontroller's timing system and using Pulse Width Modulation (PWM) with feedback.

The first step to be addressed is the method for detecting motor speed. Students are made aware of the various sensing options available and the pros and cons of each option. For instance, optical switches are economical and simple to use but would not very appropriate in a dusty industrial environment. A sensor such a hall effect/gear assembly would be more rugged and more appropriate for such an environment. Therefore, we implement two scenarios of speed measurement in the lab using an optical switch with a small DC motor, and a hall effect/gear sensor with a larger ¼ hp motor. With the optical switch, students use a Schmitt trigger to square up the signal whereas with the hall-effect sensor a more complicated amplifier circuit is required to amplify and square up the signal.

In either case, the square wave pulse generated as the motor turns is used as input to the microcontroller. Here, students get introduced to the input capture feature of the HC11 timer system and its usefulness in measuring the duration of external events. Students also learn that they can measure motor speed by using this feature to measure time between rising and falling edges of the square pulse. Note that since we have two hardware setups for measuring motor speed, we also implement two different techniques for measuring this time. In one, the input capture interrupt is used whenever an edge occurs to capture the time of occurrence, and in the other, the pulse accumulator and the real-time-interrupt (RTI) feature are used to count the number of captured edges within a certain amount of time. Based on these measurements, motor speed can be easily computed. Measurement accuracy and resolution are addressed here as well. The figure below shows a prototype of the hardware setup for this experiment.

The next step in this project is the implementation of PWM with motor speed feedback to control the motor. First students are introduced to the concept of PWM and how it can be used for open loop control. They also learn how to modulate a pulse the timer's output compare functions. Then they get introduced to the concept of feedback to obtain a more stable target speed. A significant portion of time is spent studying the interface circuitry required between the motor and the microcontroller. Students get introduced to optical isolators, power supply requirements and the concept of interfacing low-level logic with inductive loads through power transistors.

Environmental Control of a Small Chamber

Since biological and agricultural engineers deal with various processes that have to be controlled such as the control of temperature inside a grain storage bin or the control of temperature inside a fermentor, we chose to introduce a project in this course that involves a similar application. This project involves monitoring and control of temperature inside a small chamber. The chambers were made out of styrofoam and they were each mounted with a thermometer (for verifying measurements), a temperature sensor (AD590) and an external temperature sensor attached to the outside of the chamber to measure ambient temperature.

The circuitry and software for this project are somewhat similar to the one developed for the motor speed controller. In this project however, students get introduced to some additional issues not encountered in the motor control project. They research different thermoelectric devices for heating and cooling the chamber. The device chosen for implementation in the lab is a Peltier heat pump. This device which is a small pellet releases or absorbs heat when current flows through the two dissimilar conductors it is made out of. This project also involves the development of a more sophisticated feedback controller since temperature outside the chamber is also used as a feedback variable.

Conclusion

In this paper, we described two microcontroller courses offered to Junior and Senior level biological and agricultural engineering students at the university of Georgia. The Senior course has also served as an elective for graduate students from various disciplines at the university such as forestry and physics. About 45 students per year enroll in both courses which are offered once a year. The feedback from students who have taken these courses has been excellent. Some students state that the advanced microcontroller course the closest to the "real world" that they have been exposed to.

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