DEVELOPMENT OF A MICROCONTROLLER LABORATORY FACILITY FOR DIRECTING STUDENTS TOWARDS APPLICATION ORIENTED PROJECTS

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Abstract *? This paper discusses the development of a laboratory facility for a microcontroller course so that students from this course can play an active role towards application oriented interdisciplinary projects.   These project groups are composed of students from three courses covering Electronics Engineering Technology (EET) and Manufacturing Engineering Technology (MET) programs of the Technology Department of Northern Illinois University (NIU). One of these courses was Tech 430: Microcontroller Interfacing and Applications.   For these student projects, microcontroller has served as the system controller and the students from this course contributed towards these project with a knowledge of microcontroller in terms of hardware system design and programming.*

INTRODUCTION

With the advent of VLSI technology, microcontrollers serve as an embedded controller and could be found within a range of household, industrial and commercial products; such as engine control, washing machines, microwave ovens, photocopier and industrial automation producds [1]. Towards this, the Technology Department of NIU introduced a senior level course on microcontroller (Tech 430: Microcontroller Interfacing and Applications) within their undergraduate EET program. The only pre-requisite for this course is a Microprocessor course, so that students who are coming to this course have some background in microprocessor hardware and assembly language programming. Traditionally, Tech 430 was an independent course with mostly lecture and some laboratory components.

Considering current demand from industry towards simultaneous engineering, during the Fall 2002 three Faculty members from the EET and MET undergraduate programs of Technology Department of NIU, are teamed up to offer interdisciplinary projects to student groups. These student groups consist of students from the microcontroller course along with the students from the Computer-aided Machine Design (Tech 414) and Computerized Integrated Manufacturing (Tech 420) courses.   Details of this interdisciplinary project effort are going to be reported through reference [2].

Responsibilities of the students from the microcontroller course involves the design and development of transducers and signal processing circuits, along with the incorporation of a microcontroller as the system controller. The Tech 430 course is going to prepare the students for the microcontroller part of the project while they were exposed to remaining areas through other earlier courses within the EET program. This course has both lecture and laboratory components.   The challenge for delivering this microcontroller course was that the topics needed to be introduced in an orderly manner so that knowledge from this course can be used towards the interdisciplinary projects, which are going to be offered during the same semester period.

This paper is going to report the areas covered by the laboratory experiments, description of hardware and software used, course administration and assessment method, along with a discussion on the nature of the interdisciplinary projects and how they linked with this course.   To demonstrate the significance of the microcontroller course towards this project, a general discussion about the nature of these interdisciplinary projects is presented.

MICROCONTROLLER LABORATORY EQUIPMENT

Although this course has been offered through the EET undergraduate program for sometime, new laboratory equipment were acquired just before the starting of the Fall 2002 Semester. The underlying objectives towards choosing the laboratory equipment are:

a) Flexibility in programming;
b) Transparency towards microcontroller's internal operation while executing a program;
c) Ability of interfacing with other process trainers so that one can experiment with process control operations through the microcontroller trainers;
d) Flexibility of interfacing with any other external systems and processes;
e) Robustness.

After a considerable amount of research, a range of products was identified which matches all the above criteria. These products are from Feedback Instruments [3]. These

are MC11 Trainer Board, Application Board, WinMC11 and Crossware Embedded Studio software. An interfacing board is required while putting these two boards together. This interfacing board (CABMC11) is also supplied by Feedback Instruments. The MC11 board is accompanied with a third party product software called *Crossware Embedded Studio* for user software development, and *WinMC11* for downloading the compiled user program to the target board and for system monitoring.

MC11 is a single board computer based on 68HC11 Microcontroller. This is a small but powerful developmental tool with an 8-bit microcontroller unit (MCU). It is designed for use as an evaluation and training aid, but may just as effectively be used as a stand-alone controller. This unit should be linked to a host PC via its serial port in order to allow the development and execution of user programs (Figure 1).
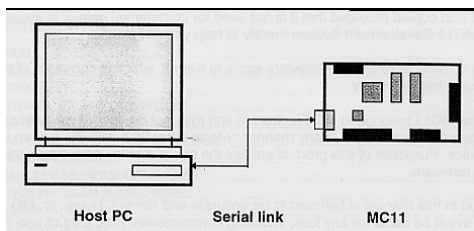

FIGURE. 1
CONNECTION DIAGRAM OF MC11 BOARD WITH A HOST PC.

The features of this MC11 board are [4]:

a) MCU contains 256 bytes of RAM and 512 bytes of EEPROM;

b) A ROM-Resident monitor program allows short user programs to be quickly assembled and debugged on a line-by-line basis. The ROM size is 8Kbyte. Longer programs may be assembled on the host PC, loaded into MC11, then run and tested under the control of a monitor program;

c) 8-Kbyte of RAM for user programming;

d) Two IDC connectors (Port-1 and Port-2) permit easy interfacing to peripheral hardware. Port-1 allows direct connection to a wide range of standard target systems;

e) An expansion port (Port-3) enables further expansion of the system.

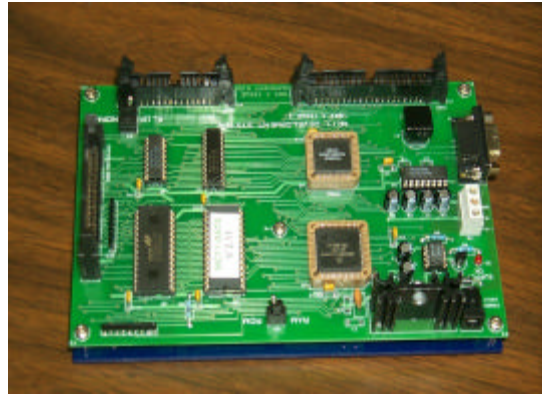The picture of an MC11 board is shown in Figure 2.

FIGURE. 2
MC11 BOARD WITH MC68HC11 AS MCU.

The Application Board is designed to provide the student with a vehicle to attain the skills required to develop systems which respond to 'real-time' events. This board contains a cross section of process/systems on a single compact board that can be interfaced to various controlling systems via a single 40-pin IDC connector. In this laboratory course this board is to be used with the MC11 DATS board. Figure 3 shows a picture of this application board.
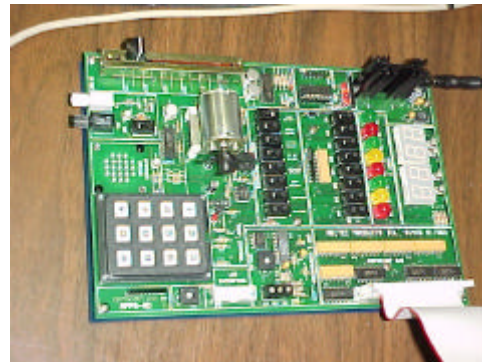

FIGURE. 3
APPLICATION BOARD INTERFACEABLE WITH MC11 BOARD.

The Application Board has the following facilities [5]:

a) Eight large LED;

b) Eight-slider switch;

c) Two dual seven segment displays;

d) A DC motor equipped with a three-blade propeller. The propeller is placed in such a way that it interrupts an IR LED and sensor. The output of the sensor is converted to a digital signal and is readable on one of the outputs from the Application Board. This

signal can be used in a close-loop manner for the motor speed control.

e) A resistive heating element and a semiconductor temperature sensor for heat control applications. The heating element is in contact with the temperature sensor. The motor propeller can be made to pass air over them, causing a cooling effect;

f) A standard telephone type 3 X 4 matrix keypad is provided for entering user response towards a program;

g) A fiber optic transmitter and receiver module for fiber optics communication experiments;

h) An 8-bit Digital to Analogue Converter (DAC) and a comparator to enable the programming of Analogue to Digital converter (ADC) functions;

i) A slider potentiometer providing a variable analogue voltage;

j) A speaker which can be driven either from a digital signal or from the output of the DAC;

k) An LCD interface circuit & LCD display;

l) A stepper motor control circuit.

The application board is controlled by two 8-bit ports (port-1 and port-2), via a 40-pin IDC connector. Some of the board functions are enabled/disabled using the control switches SW1 - SW9. SW1 to SW8 are grouped in the center of the application board whilst SW9 is situated in the fiber optic link area. The Applications Board can be connected to the controlling system (MC11) via a 40-way IDC connector. A picture of a MC11 board interfaced with an Application Board through an interface adapter is shown in Figure 4. In addition to this MC11 board this Application Board can also be used with other trainers developed by Feedback Instruments.

FIGURE. 4
APPLICATION BOARD INTERFACED WITH MC11 BOARD THROUGH A
CABMC11 INTERFACE ADAPTER.

The *Crossware Embedded Development Studio* is a window-based sophisticated development environment, which can be used for developing user programs for embedded applications. This provides a user-friendly interface to the embedded development tools with a project-based approach to help and organize the work. On top of this the software has an integrated editor with sophisticated coloring and integrated terminal emulation facilities. Students can develop application programs by using assembly language or a high level language, such as C. In this laboratory class, assembly language was used for program development purposes. The appearance of this software window is shown in Figure 5. The top left window is for file management; the top right window for code writing and the bottom window for message generation during the compilation and building processes. The compilation and building process produce a file in S-format within a host PC. This S-format file needs to transfer to the target board (MC11) for its execution.
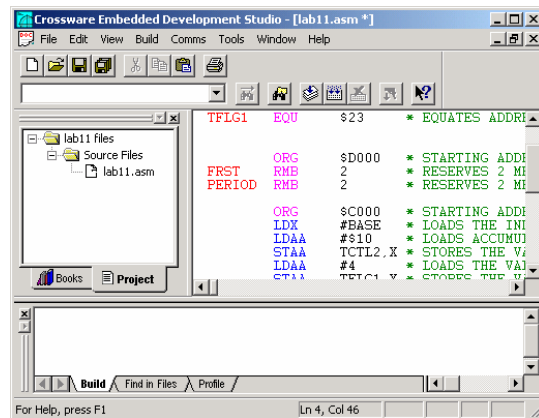

FIGURE. 5
CROSSWARE EMBEDDED DEVELOPMENT STUDIO WINDOW.

There is special software, called *WinMC11*, which is used to download the compiled S-format file to the target board. This software provides a powerful means of accessing various registers of a microcontroller through a user friendly Graphical User Interface. Considering the educational application in hand, this feature played a very important role towards choosing this system. The main window for this software is shown in Figure 6. Various buttons on the top right side and the menu at the top left side are used for program execution, monitoring, and memory management operations.
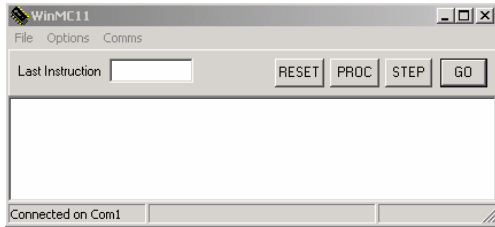
FIGURE. 6
WINMC11 WINDOW FOR DOWNLOADING AND SYSTEM MANAGEMENT.

A number of additional windows, which can be generated from this window, are described below. The first one is the "Register" window (Figure 7), which is for displaying the microcontrollor's internal register values. The registers showing within this window are accumulators, stack pointer, index register, program counter, condition code register, etc.
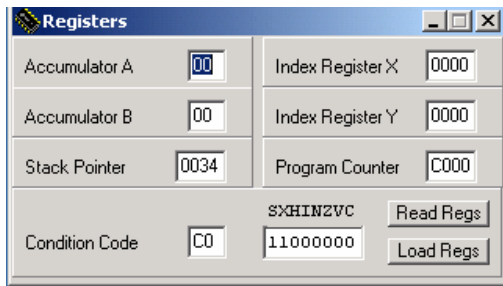

FIGURE. 7
REGISTER STATUS MONITORING WINDOW.

Contents of the system's memory can be viewed through the "Memory Dump" window (Figure 8). This window shows the status of a block of memory area starting from a given address location.
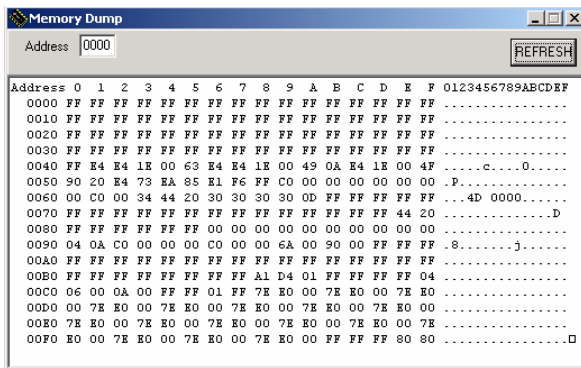

FIGURE. 8
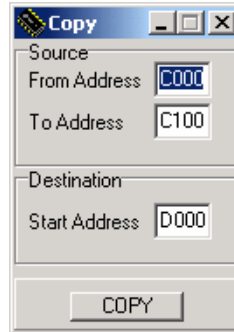WINDOW SHOWING THE CONTENTS OF A GROUP OF MEMORY LOCATIONS.

FIGURE. 9
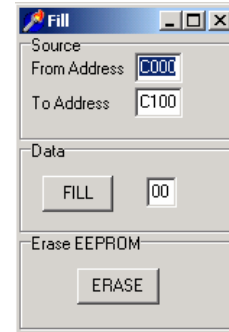WINDOW SHOWING THE COPY
OPTION OR MEMORY LOCATIONS.

FIGURE. 10
WINDOW SHOWING THE MEMORY
CONTENTS MANIPULATION AND
ERASING OPTION.

Similarly, memory contents can be copied from one location to the other through the "Copy" window (Figure 9). The system's memory locations can be erased or filled with a given value, along with erasing the complete EPROM through the "Fill" window (Figure 10). In addition to this, four breakpoints can be set to debug a given program. This window is called the "Breakpoint" window (Figure 11).
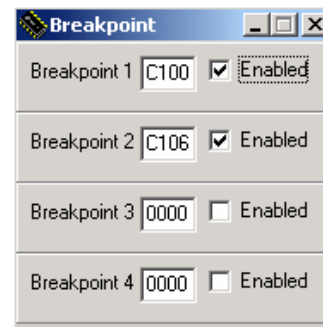

FIGURE. 11
WINDOW SHOWING THE BREAKPOINT SETTING OPTION.

MICROCONTROLLER LABORATORY EXPERIMENTS

The main point of focus for the laboratory development process was to prepare the students to contribute with their full potential towards interdisciplinary projects.

The topics covered by the laboratory sessions within this microprocessor course can be categorized as addressing modes, mathematical operations, interfacing concepts, DAC and ADC operations, counter/timer, and interfacing applications. The specific topics addressed by each group of these laboratories are discussed below.

Addressing Modes

This group of laboratory sessions is designed to familiarize the students with various addressing modes and instruction sets. The other objectives are to familiarize the students with "Crossware Embedded Development Studio" and "WinMC11" for programming tasks. Particularly, this group of laboratory experiments were designed to become familiar with various internal registers of the microcontroller along with system memory management through WinMC11 software, and also through various addressing modes.

Mathematical Operations

At this point the students became familiar with using instruction set and addressing modes for manipulating data among various memory locations. They were asked to program for mathematical operations like addition, subtraction, division, and multiplication. This section also focuses on the program design techniques. Some of the experiments, which came under this section, were data manipulation using arithmetic operations and multi-bit multiplication.

Programming Experiments

At this stage of laboratory experiment, students gained sufficient knowledge of using appropriate instructions and addressing modes for a specific task. Developing logical analysis and other methods to solve a problem was targeted through this set of experiments. Some of the techniques, like branching, comparing and looping were emphasized. As they play a critical role in complex programs. Searching for an element within an array and isolating positive and negative numbers in a block of data were some of these tasks.

Interfacing Concepts

The ultimate application of a microcontroller is to operate a system or plant, such as engine control/management, vending machine operation, microwave oven control, etc. This requires the microcontroller to connect with other hardware devices and exchange information to perform specific task(s). This group of laboratory sessions introduces the input/output interfacing experiments. At this point students are asked to use the Application Board to operate and control some of the available processes within the board. The experiments implemented under this group of laboratory sessions are configuring a port for input or output operation, data collection and delivery through an assigned port, motor speed control, temperature control, stepper motor control, etc. This section forms the foundation towards the implementation of the interdisciplinary projects.

Counter/Timer Applications

In this laboratory group the students are introduced to MCU's timer unit, which is used for driving output peripheral interface circuits. In real life applications where microcontrollor controls the output devices, it is vital to know the time of an input event. The timer functions such as input capture, output compare and pulse accumulator are introduced through this group of laboratory sessions. In these sessions students utilized the capabilities of generating various wave shapes with specific frequency requirement and measuring pulse width.

DAC and ADC Conversions

This group of laboratory sessions dealt with the operation of DAC and ADC conversion for interfacing applications. Most real-life processes and interdisciplinary projects require the microcontroler system to deal with analog signals. The MC11 board is provided with DAC and ADC capabilities. This made the interfacing task easier for the students. In this group of laboratory sessions students need to identify various registers and memory locations used for this DAC and ADC conversion within the MC11 board. They also need to identify the hardware used for this process along with the significance of conversion accuracy towards the system operation. The last phase of this group of laboratory sessions was to build signal-conditioning circuits to control the gain and offset of the external signals to match the specifications of the microcontroller.

LABORATORY STRUCTURE AND ASSESSMENT

The course was designed to prepare the students for practical application of microcontroller with an immediate application towards the interdisciplinary projects. This was mainly a laboratory-based "do to know" nature of course. The class meets for couple of theory classes to familiarize the students with basics of operations. Custom prepared handouts were provided for each laboratory session. These handouts are composed of a sample program followed by an assignment task. The students are asked to implement a sample program and observe its components and features. This helps them to understand the underlying rules and practices to solve a problem of similar nature. With such an understanding they can perform a given task and demonstrate the outcome to the course teacher or the Teaching Assistant (TA). While in a laboratory session, Faculty and TA asked questions to student groups to highlight the main components of that session.

At the end of each laboratory session each group needed to submit a report along with a copy of the developed program. Apart from the solution of assignment task, these reports contain an abstract and conclusion section. The

student groups are also responsible to come up with a suitable title for their laboratory sessions.

Submitted laboratory reports are assessed for the understanding of the topics and session objectives, presentation, and technical writing. Comments were made on these reports and returned back to the student groups as a part of formative assessment, so that students can improve their performance for future laboratory sessions. The marks for each laboratory report the distributed as: title-5%, abstract 20%, conclusion 10% and 65% towards the assignment task performed.

INTERDISCIPLINARY PROJECTS

The main objective of these interdisciplinary projects was to design products or systems through a simultaneous engineering approach. The student groups are composed of students from two other courses who are not enrolled in this course. The three key areas that are addressed through these interdisciplinary projects are:

a) Product design and realization;

b) System control and electronics;

c) Manufacturing processes and automation.

One of the main objectives for these laboratory sessions was to prepare the students to maximize their contribution towards the interdisciplinary projects through the development of system control and electronics. The tasks of students from the Tech 430 course were to implement the electronics and microcontroller part of the projects in line with simultaneous engineering philosophy. Detailed findings from this interdisciplinary project approach are described in reference [6].

There are a total of nine interdisciplinary projects, which student groups have performed after having experience from this course. These projects are:

a) Design and development of MC Hopper;

b) Design of a safe room within a house;

c) Motorcycle gear-positioning indicator;

d) Alternative powered vehicle;

e) Active headlight system for automobiles;

f) Smart garage system;

g) Automated pill dispenser;

h) Automobile obstacle detection system;

i) Daylight sensitive light intensity control system.

For all these projects the students from Tech-430 played an important role towards the incorporation of microprocessor as a system controller and also through the development of necessary electronics for incorporating sensors and actuators as a part of the systems. To demonstrate the role played by the students from Tech-430, one of the above projects (Automobile obstacle detection system) is described here by highlighting its main features.

The designed system is to be a part of an automobile and will warn the driver when the vehicle is too close to other objects (Figure 12). The detection range for this device can be adjusted from 0.2 to 1 meter. This is mainly for assisting the driver during the parking of a vehicle. The designed system consists of an inferred distance sensor as an input, and a light and a buzzer as the outputs. A user would have the choice to select which form of output they would like to have for each case. A microcontroller played the role as the system controller. After necessary signal conditioning, the distance sensor output is fed to the microcontroller for decision-making. Through a user input, users can select the distance for which the alarm needs to be triggered. The outputs are activated by the microcontroller through necessary signal conversion and amplification.

FIGURE 12
PROTOTYPE OF AN AUTOMATIC OBSTACLE DETECTION SYSTEM.

In terms of microcontroller involvement for this specific, project students from this class needed to use the techniques learned for data manipulation, input/output interfacing and DAC and ADC processes. Assembly language programming was also used for this project.

CONCLUSION

This paper describes the development of a microcontroller laboratory course in terms of selecting suitable laboratory equipment and experiment design, so that students from this course can play an active role towards the development of a product for interdisciplinary projects using a simultaneous engineering approach. The students are introduced towards the various components of a microprocessor system along with the assembly programming techniques for data manipulation, arithmetic operations, input/output interfacing, and DAC and ADC conversion, along with their significance towards a systems performance.

The active contribution of the students from the Tech 430 class towards this project and the success of the

interdisciplinary projects signify the impact of strategy towards the laboratory development approach.

ACKNOWLEDGEMENT

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