

## Laboratory for Microcontroller Applications

Janos L. Grantner, Ramakrishna Gottipati, Paolo A. Tamayo, and David Florida

Department of Electrical and Computer Engineering  
Western Michigan University  
Kalamazoo MI 49008-5329, USA

janos.grantner@wmich.edu, r.gottipati@wmich.edu, p3tamayo@wmich.edu,  
david.florida@wmich.edu

### Abstract

The course ECE 451 Microcontroller Applications [4] is offered by the Department of Electrical and Computer Engineering of Western Michigan University and it is a required course for students majoring in Computer Engineering. In order to pass the course students need to pass the embedded lab as well. This course is also offered as an elective to graduate students under ECE 595. The graduate section of the class has an extra project assignment. The objective of the course is that students will develop skills in the areas of embedded systems design, microcontroller systems interfacing, hardware/software integration, and debugging while working with a contemporary microcontroller platform and using C as their programming language.

The Motorola/Freescale MC9S12DP256 Microcontroller EVB kit by Technological Arts [5] along with the ICC12 IDE software by ImageCraft [6] has been used in the lab for about two years. The rationale for this decision is based upon the fact that this chip is a powerful member of the HS12 Family of microcontrollers that have been a dominant choice for automotive embedded systems. In addition, the HS08 Family that has a quite similar architecture has been used in household appliances made by Whirlpool. Active industrial and academic Web sites along with a user group mostly from industry provide strong support.

Debugging the programs is done by using the MicroBDM12SX Module by Technological Arts along with the NOICE12 debug software by NoICEDebugger [7]. Students develop C programs for almost all lab experiments. Initially, the programs are loaded into the on-chip RAM memory to facilitate debugging. The finalized code is programmed in the on-chip FLASH area and is demonstrated again. The laboratory experiments include interfacing to parallel I/O ports, non-TTL interface, external interrupts, Main Timer overflow interrupts, Input Capture, Output Compare, pulse width modulation (PWM), analog I/O interface, asynchronous serial communications interface, SPI (Serial Peripheral Interface) interface, and CAN (Controller Area Network) interface.

In addition to the lab experiments, both ECE 451 and ECE 595 students are required to complete a lab project, which relies on using quite a few of those programmable modules of the

microcontroller that are covered in the lab. ECE 595 students are also assigned a midterm project (the development of a LCD interface). All students are required to purchase their own Microcontroller EVB, a student license of the ICC12 IDE software, and a Parts Kit for the labs and projects.

In the first section of the paper, we will summarize the work done in the class. The second section will focus on the laboratory experiments and the projects in detail. The third section will outline a few planned future developments of the course.

## **1. Introduction**

Microcontrollers are a result of the evolution in microprocessor architectures and manufacturing technologies which produce smaller devices. A microcontroller is a complete computer system optimized for embedded control and it encapsulates an entire processor along with memory and all sorts of I/O peripheral modules on a single piece of silicon. Microcontroller applications include automotive electronics, avionics and home appliances just to name a few.

The Microcontroller Applications course and the embedded Microcontroller Laboratory have been developed in the Department of Electrical and Computer Engineering Department such that its main emphasis is on the various aspects of real-time embedded control applications. This course is a 3 credit hour course with 2 hours of lecture per week and a 3-hour lab session per week. The lab makes up 30% of the course grade and students are required to pass the lab in order to pass the course. The course is offered every Fall and Summer I terms. Most students use this course as a solid foundation for their Senior Design projects. For graduate students this course helps them to succeed in their 600-level classes. Apart from the laboratory assignments the course work also comprises of homework assignments, class and lab projects, and exams.

### **2.1 Class Work**

The classwork in the microcontrollers applications course include 2 hours per week of lecture sessions. The in-class lecture sessions cover for topics as follows; detailed explanation of the architecture and operation of the CPU core, of the various programmable modules, memory maps, interfacing techniques and their real word applications, and a critical timing analysis for external memory interfacing.

The lecture sessions also include a brief explanation of the next week lab to be performed, as well as hints on how to approach the lab problems, and the ways of carrying out the Prelab assignments. All of that information is posted and updated every week on the Class Web Page. The Web Page is the main source of information for the class.

There is no required textbook for the course. The Class Web Page, the Motorola MC9S12DP256 Instruction Manual, the CPU Reference Guide are the main sources of information for the class. Students are encouraged to buy the reference textbooks referred to on the Class Web Page. It also contains information about the weekly labs, prelabs, various datasheets of the MC9S12DP256 microcontroller, weekly lectures, homework assignments and solutions to the homework assignments etc.

The most important and handy section of the Class Web Page is the tutorials section which provides detailed information and step-by-step procedures on how to work with the various tools and software being used in the class. Some of the tutorials that are currently available are the ICC12 User Guide, the NOICE User Guide, the Flash Programming Tutorial and the C Programming Tutorial. They have been developed by the authors of this paper.

Class work also includes homework assignments every week and they are due the following week. Most of the homework assignments include real world applications as well as mathematical calculations to achieve the required timing details, and a C program. Students are expected to give a detailed explanation of their procedures to solve the problem. The assignments cover problems such as peripheral data interface, digital signal interface, a frequency detector system, analog to digital conversion, and a printer interface system. Solutions to the assignments are provided by the class instructor and are regularly posted on the Web Page.

Apart from all of this students are required to take a midterm exam and a final exam that test the students' ability of problem solving. The two exams in total comprise of 50% of the course grade for ECE451 students and 45% of the course grade for ECE 595 students.

## **2.2 Lab Work**

The topics covered in class are mostly practiced in the lab during the lab session of that week. The lab sessions provide a hands-on approach and yield a good understanding of the operation and programming of various peripheral modules, and interface techniques that are supported by the 'DP256 microcontroller. The lab meets every week for a 3 hour session during the Fall semester and meets twice every week in the accelerated the Summer1 term. All labs are single session ones but the CAN Bus interface lab which is a two-session lab.

The laboratory is made up of 10 workstations and students typically work in groups of two throughout the semester. Each workstation consists of a Digital Voltmeter, a Function Generator, an Oscilloscope, a 16-channel Logic Analyzer a MicroBDM12SX module and a desktop computer by Dell. Regulated DC power supply units are built into the benches. The computer is equipped with the ICC12 IDE software for developing C programs and the NOICE12 software for debugging purposes. Students are required to buy their own microcontroller boards and a 6-month license of the ICC12 IDE. They use their boards during the lab sessions starting with Lab 3. In addition, students are also required to buy the parts required for the lab experiments and for their lab projects.

The microcontroller EVB Kit by Technological Arts is shown in Figure 1. It provides the resources as follows: 76 I/O lines, 16 ATD (analog-to-digital) channels, 2 CAN modules, 2 RS232 modules, I2C bus, SPI bus, 8 PWM channels, 8 enhanced capture timing channels, 256Kbyte Flash, 12Kbyte RAM, and 4Kbyte EEPROM. ECE595 students should have Supplement Parts Kits for their extra design project.

The ICC12 IDE (Integrated Development Environment) software by ImageCraft is being used in the lab for software development (Fig. 2). All lab experiments are developed using the C language and are first downloaded into the on-chip RAM of the microcontroller to facilitate debugging. After the tests have proven that a program meets the required specifications, it will

be downloaded onto the Flash and the system will then be powered up again to verify its performance while the EVB is disconnected from the computer. The main purpose of downloading the code to the Flash is to give the students experience with respect to developing stand-alone embedded systems.



Figure1: MC9S12DP256 microcontroller EVB Kit by Technological Arts

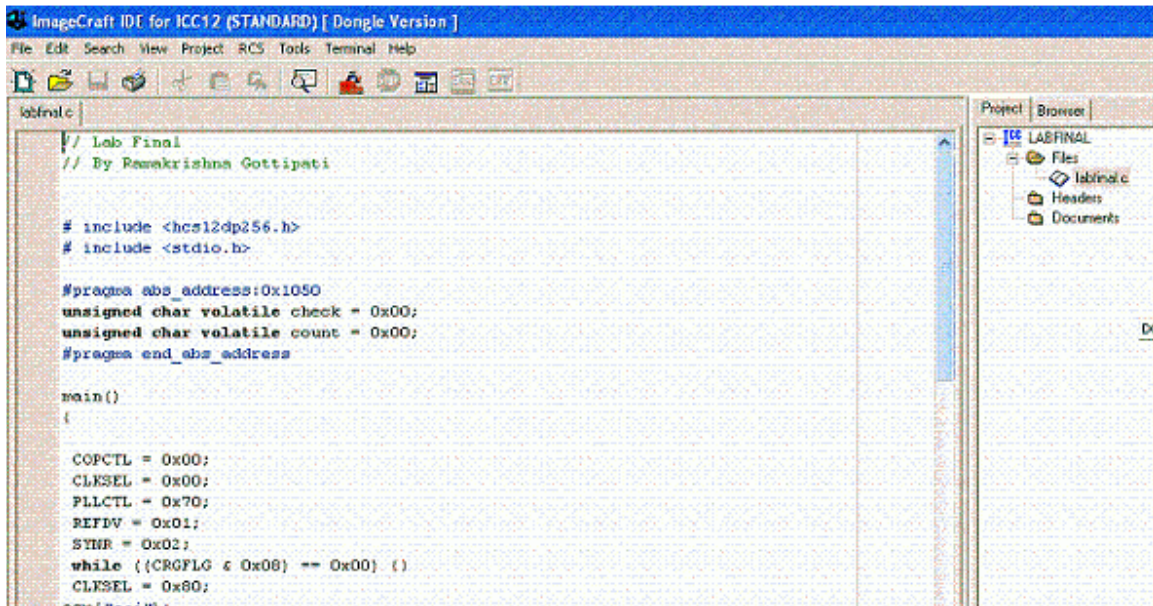


Figure 2. ICC12 IDE software environment by ImageCraft

The MicroBDM12SX debugger module (Fig. 3) along with the NOICE12 debug software are used for debugging activities in the lab. The NOICE software environment is shown in Fig. 4. This debugger provides information on the contents of memory locations of the microcontroller during run time. This feature helps the students big time in debugging their programs while they are running. The ECE 451/595 Laboratory environment is shown in Fig. 5.



Figure 3. MicroBDM12SX debugger

Each lab assignment is broken up into a prelab and a set of lab tasks. Students are required to submit the prelab at the beginning of the lab session every week. The prelab calls for a schematic diagram, timing calculations to meet the specs of the lab, and pseudo-code for the tasks to be done. Students are required to turn in their Lab Reports after they have completed a lab session. The report consists of a detailed schematic diagram, timing calculations, C code, assembly list files, Logic Analyzer and/or oscilloscope screenshots and a conclusion. Each lab is assigned a total of 12 points with 3 points for the prelab and 9 points for the lab.

The laboratory experiments are enumerated as shown below:

- Lab 1: Introductory Lab (Provides introduction to the equipment and the software)
- Lab 2: Elementary Programming for the MC9S12DP256 Microcontroller (Brief introduction to C programming techniques)
- Lab 3: Basic Parallel Output and Software Delay Loops
- Lab 4: Parallel Input/Output and External Interrupt
- Lab 5: Programmable Timer and Output Compare
- Lab 6: Input Capture and Pulse Width Modulation
- Lab 7: Analog Input/Output Interface and Simple Digital Signal Processing
- Lab 8: Asynchronous Serial Communications Interface
- Lab 9: Serial Peripheral Interface (SPI)
- Lab 10: CAN Bus Interface.

Lab1 introduces the students to the laboratory equipment and the software tools being used in the lab. The instructor presents the ICC12 IDE software development tutorial and the NOICE 12 debugger software tutorial to demonstrate the use of the tools available in the lab. The instructor also provides three assembly/C programs to the students in order to practice building, downloading and running programs.

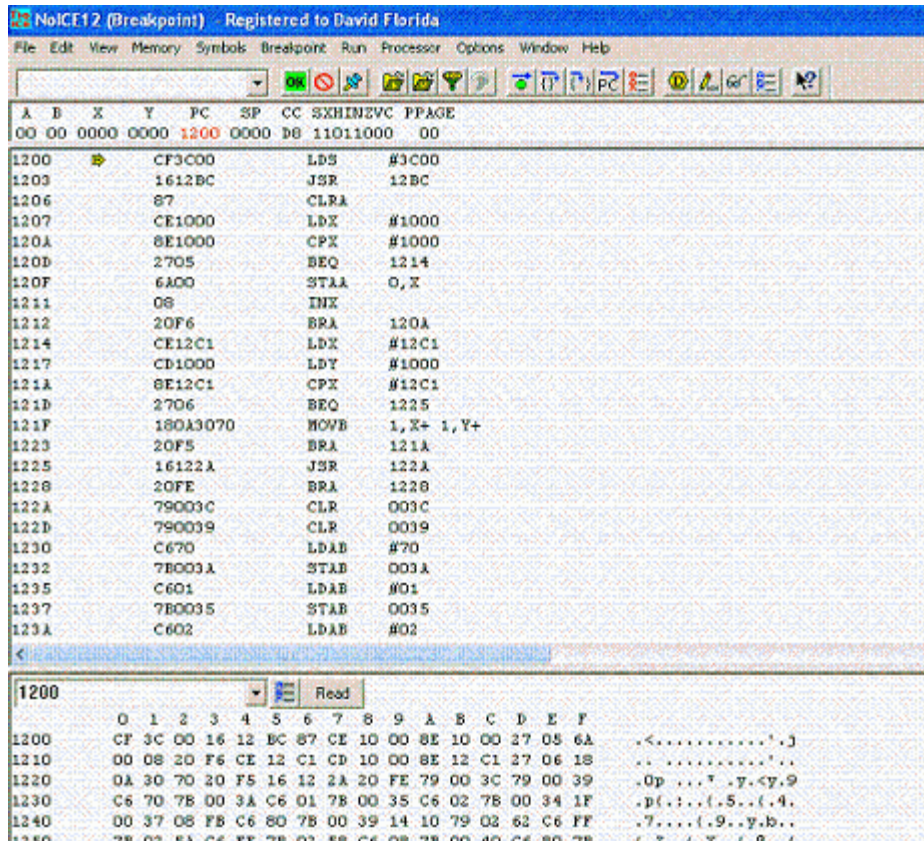


Figure 4. NoICE12 Debug Software Environment



Figure 5. ECE 451/595 laboratory environment

Lab 2 introduces the basics of C programming to the students. The lab mainly concentrates on basic C programming skills such as memory allocations, array declarations, basic loops, if conditions, pointers and work with positive and negative numbers. Students develop six C programs (addition, subtraction, sorting arrays, sorting positive and negative numbers), then build and execute them from the RAM area of the microcontroller.

Lab 3 introduces the concepts of basic parallel output interface and software delay loops, respectively. The main idea behind this lab is to begin to expose students to interfacing techniques and to develop timing delays by software rather than working with the timer modules available. In this lab students are required to output a changing, visible data pattern onto the LED's through a general purpose I/O port and to display each bit pattern for a particular amount of time. The required time delay is obtained using the concept of software delay loops. Starting from this lab students make use of logic analyzer screen shots to demonstrate that the timing specifications are met.

Lab 4 brings in the concepts of parallel input/output interface and external interrupts, respectively. Starting from this lab Flash programming is also introduced to the students and they are required to demonstrate their programs running from the Flash. The 8-bit input data that is read from a DIP-Switch module is broken up into two 4-bit nibbles. The program should then perform the required operation on those nibbles and display the 8-bit result on the LED's. The flow chart depicting the tasks for the parallel input/output and the external interrupts is shown in Fig. 6.

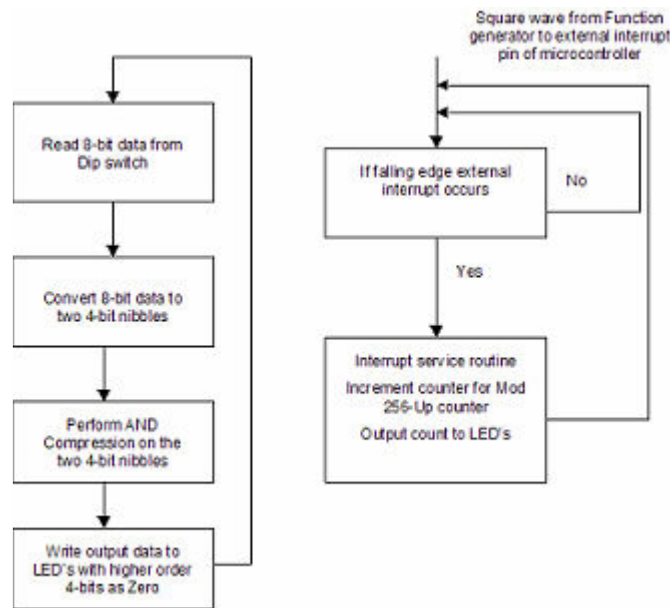


Figure 6. Parallel Input/Output and External Interrupt

Labs 5 and 6 introduce the concepts of Timer Overflow, Output Compare, Input Capture and Pulse Width Modulation (PWM). In Lab 5, the Main Timer Overflow interrupts are employed to control a relay by a periodic output signal that is to energize and then de-energize the relay coil. The task flow is shown in Fig. 7. For the Output Compare, a periodic digital output signal of particular frequency and duty cycle should be generated and verified using a logic analyzer. In Lab 6, students work with the Input Capture and PWM functions, respectively. The frequency, as well as the high and low times of a digital input signal from a function generator should be measured using Input Capture. In addition, a PWM port should be utilized to generate a periodic digital output signal of specified frequency and duty cycle and the results should be verified using a logic analyzer. The final assignment in Lab 6 is to combine the

functions of the PWM, Output Compare and Input Capture modules to implement a complex input/output signal interface. The task flow is shown in Fig. 8. A signal from a function generator is measured using the Input Capture. Based upon the value of the measured frequency either the PWM, or the Output Compare module is to generate specific digital output signals.

In Lab 7, students are exposed to Analog Input/Output interface and simple Digital Signal Processing techniques. A sinusoidal analog input signal of low frequency is generated by a Function Generator. The signal should be clamped between 0V and approx. +4V because the maximum value of the analog  $V_{DD}$  for the Analog-to-Digital (ATD) modules of the 'DP256 microcontroller is about +5V. In order to provide for an analog output signal, students should interface an external D/A converter IC (DAC) to one of the parallel ports of the microcontroller. Students are required to develop a program to execute the tasks as follows: the analog input signal is to be sampled and converted to digital by means of an ATD module. Then the program should perform a scaling of the input signal by calculating the formula  $y = a \cdot x + b$  where  $x$  is the converted input signal, and  $y$  is a digital value to create an analog output signal. Constants  $a$  and  $b$  are chosen such that to introduce a positive bias voltage with respect to GND and to scale the peak-to-peak value of the analog output signal in a way that it should not exceed +5V. The value of  $y$  is then copied to the external DAC. The performance of the system is verified by oscilloscope.

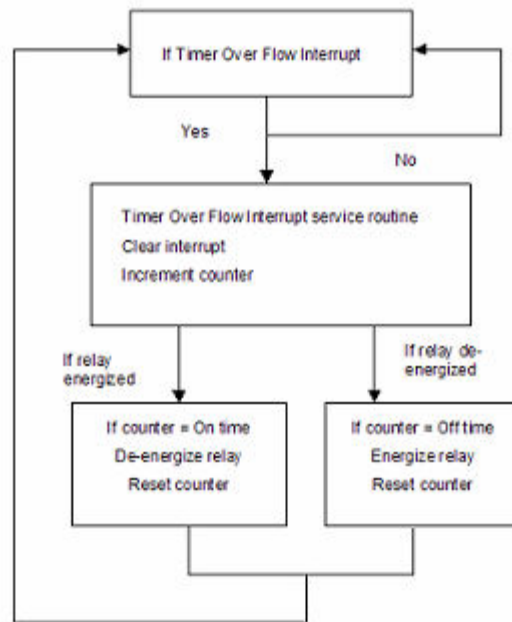


Figure 7. Energizing and De-energizing a Relay Using Timer Overflow Interrupts



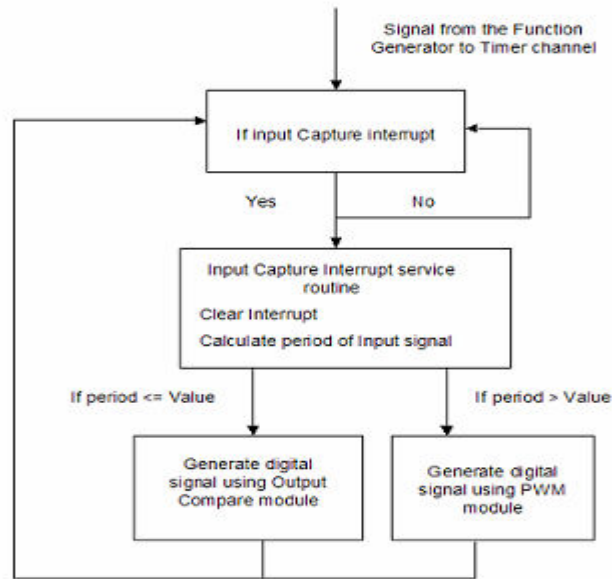


Figure 8. Generating Digital Signal by Using the Output Compare/PWM Modules

In Lab 8, students are required to implement an asynchronous serial communications port using one of the SCI modules of the microcontroller and then develop a C program to operate it in Full-Duplex mode. Two groups connect their EVB Boards together to send and receive different messages of up to 16-characters.

Lab 9 introduces the concept of the Serial Peripheral Interface (SPI). Students should implement a SPI port and develop a C program to operate it in Half-Duplex mode. Again, two groups are required to send/receive data blocks of 16-characters.

In Lab10, a pair of collaborating student groups should implement a Controller Area Network (CAN) communications port and develop a C program to send and receive messages of 32-characters simultaneously using interrupts, filters and message ID's for the data being transferred. Lab10 has a bonus assignment, too, that is worth an extra 25% (+ 4 points) of the whole Lab. It requires a minimum of four groups. For the bonus all the groups are required to interface to the same CAN Bus but will exchange messages only with their designated partners even though all microcontrollers transmit and receive data simultaneously as shown in Fig. 9. This assignment is a very convincing demonstration of the properties of the CAN Bus using ID's and masks to filter messages.

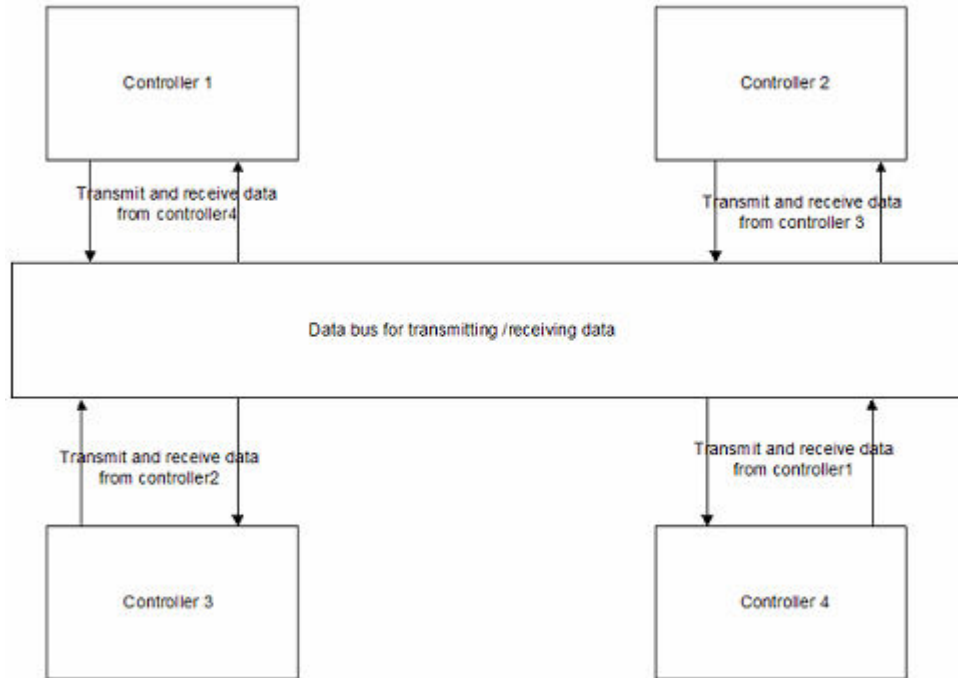


Figure 9. Controller Area Network Interface

In addition to the lab experiments described above students are also required to complete a lab project that makes up 15% of the course grade for ECE 451 students and 10% for ECE 595 students, respectively. The project involves the use of I/O ports, external interrupts, Timer Overflow interrupts, as well as the Input Capture, and Pulse Width Modulation modules for simulating a controller for a conveyor belt in an industrial setting. ECE 595 students are also assigned another design project which comprises 5% of their course grade. That project is about to interface a 20x2 character LCD module to the microcontroller. The lab concludes with a Lab Final Exam which tests the ability of each student to complete a given task in 90 minutes. The Lab Final is worth three labs. The total of the lab scores makes up 30% of the course grade.

### 2.3 Future Work

Future work involves the addition of an external bus interface lab that will interface the microcontroller to an external memory device such as SRAM or FLASH. It is expected that Freescale will soon roll out a new version of the 'DP256 microcontroller with improved timing for the External Bus. When that chip becomes available the new lab will be developed. In addition, the SPI lab will be upgraded from Half-Duplex mode to Full-Duplex mode. By developing a suitable cable set with connectors the bonus part of the CAN Bus lab will be extended such that all groups in the lab will connect to the same data bus to send and receive data to/from multiple controllers simultaneously.

### 3. Assessment

The assessment of the course and the lab [8] resulted in a good, positive response from the students on the overall quality of the class and also on the experiments done in the lab. Some of

the assessment questions that were given to students with respect to the quality of the class/lab are listed below.

- a. How do you rate the overall quality of this class?
- b. How much have you learned in this class?
- c. Did this course improve your understanding of concepts and principles in this field?
- d. Did you improve your ability to communicate clearly about this subject?
- e. For this course, how do you rate the stimulation of thinking?
- f. Did you improve your ability to solve real problems in this field?
- g. I gained skills during this course to help me learn independently.
- h. This course broadened my perspective of working in a global/societal context.
- i. This course helped me to fulfill some of my personal goals.

These questions were rated by 23 students who took the course in the Fall 2004. The assessment was rated on a scale of 0 to 5. The mean for the above questions are as shown in Fig. 10.

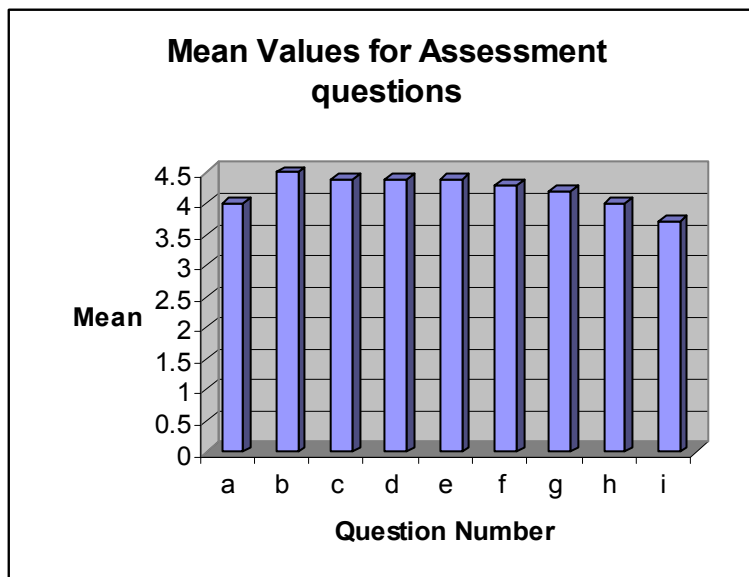


Figure 10. Mean Values of the Student Assessments

#### 4. Conclusion

Various aspects of the Microcontroller Laboratory developed in the Department of Electrical and Computer Engineering at Western Michigan University are presented in detail. The lab is embedded in the ECE 451/595 Microcontroller Applications course. This course is very useful for students starting their Senior Design projects involving microcontrollers. Also this course gives the required skills and knowledge to graduate students to excel in their higher-level classes.

#### References

- [1] CPU12 Reference Manual – M68HC12 & HCS12 microcontrollers, Rev 3.0, 2002
- [2] M68HC12 Family Data Sheets, Rev 5.0, 2003
- [3] MC9S12DP256 Advance Information – Motorola, Rev. 1.1, 2000
- [4] <http://homepages.wmich.edu/~grantner/ece451>
- [5] <http://www.technologicalarts.com>

[6] <http://www.imagecraft.com>

[7] <http://www.noicedebugger.com>

[8] The ICES Catalog, Division of Measurement and Evaluation, University of Illinois at Urbana-Champaign

## **Biographical Information**

### **JANOS L. GRANTNER**

Janos L. Grantner is a Professor of Electrical and Computer Engineering in the Department of Electrical and Computer Engineering at Western Michigan University. Dr. Grantner received the Ph.D. degree from the Technical University of Budapest, Hungary, in Computer Engineering, and the advanced doctoral degree Candidate of Technical Science from the Hungarian Academy of Sciences, in Computer Engineering, respectively.

### **RAMAKRISHNA GOTTIPATI**

Ramakrishna Gottipati is Doctoral Student in the Department of Electrical and Computer Engineering at Western Michigan University. Mr. Gottipati received the MS degree from Western Michigan University, in Computer Engineering.

### **PAOLO A. TAMAYO**

Paolo A. Tamayo is Masters Student in the Department of Electrical and Computer Engineering at Western Michigan University. Mr. Tamayo received the bachelor degree from the University of the Philippines, in Electrical Engineering.

### **DAVID FLORIDA**

David Florida is the Lab Supervisor in the Department of Electrical and Computer Engineering at Western Michigan University. Mr. Florida received the MS degree from Western Michigan University, in Electrical Engineering.