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Mechatronics/microcontroller education for mechanical engineering students at the University of South Carolina

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Abstract

A project to enhance the mechatronics/microcontroller education of mechanical engineering students at the University of South Carolina is presented. First, the state of the art in Mechatronics education is presented and discussed. Then, focus is shifted to the Mechatronics education in the Department of Mechanical Engineering at the University of South Carolina. Subsequently, the paper examines the hardware and software used for mechatronics/microcontroller education. Examples are given of the MC68HC11 microcontroller and the different evaluation boards used for (a) code development; (b) embedded applications. Then, attention is given to the software used in the mechatronics/microcontroller education. The THRSim11 comprehensive simulation and interfacing software is described. Finally, the paper discusses the interfacing between the microcontroller and the various electro-mechanical sensing and actuation components used in a mechatronics project. The use of functional modules for teaching interfacing skills to mechanical engineering students is described. The paper finishes with conclusions and further work.

Keywords: Mechatronics; Microcontroller education; MC68HC11; Evaluation boards; Embedded applications; Simulation; Interfacing software; Electro-mechanical; Sensing; Actuation; Functional modules

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1. Introduction

1.1. The need for mechatronics education

Due to the accelerated growth of electronics, computers and information technology industries, a gap has emerged between the teachings of traditional non-Electrical Engineering education (e.g., Mechanical Engineering, Civil Engineering, Chemical Engineering, etc.) and the skills expected of non-EE graduates entering the job market. A deluge of computers, sensors, microcontrollers, actuators has permeated present-day society. Microcontroller-based devices and appliances are found in all aspects of our everyday life. Even the auto industry, a traditional mechanical engineering fiefdom, is putting tens of microcontrollers in a modern automobile, and plans to increase this number multifold as new technologies are being introduced. As revealed by a recent site visit to our university by BMW auto plant representatives, hybrid propulsion, 42-Volts wiring bus, "steer-by-wire", "brake-by-wire", collision avoidance, autopilot, etc. are being currently developed, and automobiles with such capabilities will hit the market in the near future.

1.2. Mechatronics education in US and world wide

However, traditional engineering education of students covers only minimal electrical, electronics, and information technology instruction. The "high-tech" components of a non-EE education are much below expectations, in spite of clear demand. Because of this disparity, the non-EE engineering graduates entering the job market are at a considerable handicap. To acquire high-tech skills required in the job market, some mechanical engineering students try to register in upper-division EE courses. However, lacking the proper lower-division background, this practice puts them at a disadvantage, and negatively affects their GPA and course load. In response to this situation, an interdisciplinary engineering branch, that spans mechanical engineering, electronics, embedded microcontrollers/digital signal processing, controls, and information technology, has emerged under the name of *Mechatronics*. Nationwide, efforts to introduce mechatronics education in non-EE curriculum have sprung in over twenty US universities, and several worldwide [2–7,10,11,13–16,18–20].

1.3. The need for mechatronics education in South Carolina

At the University of South Carolina, the non-EE engineering students also have an acute need for education in the interdisciplinary field of mechatronics/microcontrollers. The state of South Carolina is going through an intense economical development effort focused on high-tech businesses and companies. This effort is aimed at bridging the technological divide that has placed South Carolina among the last in the nation in a high-tech economy. Critical to this statewide effort, is the development of an adequate cadre of well trained personnel that can "hit the ground running" in the growing technology-oriented job market. Akin to similar efforts going on in other places (e.g., Southern California), this will permit the building of "a critical mass of talent that local companies can draw from" [1].

1.4. Microcontroller/mechatronics education in the department of mechanical engineering at the University of South Carolina

The Department of Mechanical Engineering at the University of South Carolina (DME-USC) is well positioned to participate in promoting and developing this emerging engineering education field. DME-USC established a course for teaching microcontrollers to mechanical engineering students—EMCH 367, http://www.me.sc.edu/courses/emch367. The course consists of four major components: (a) classroom instruction; (b) homework; (c) laboratory; (d) project. The classroom instruction is focused on instilling in students the basic knowledge related to programming and using the microcontroller. Part of the classroom instruction is performed in a computer laboratory, where the students interact with simulation software on a one-on-one basis. The homework is focused on the students' understanding and retention of the concepts in a self-teaching style, and it consists of *examples* that students follow and *exercises* that the students perform and return to the Teaching Assistants via email. The laboratory consists of five sessions that gradually take the students from simple microcontroller programming through the usage of its various functions such as parallel ports, serial communication, event timing (detection and generation), DC motor tachometer, stepper motor control, and analog-to-digital conversion. The capstone of the course is a one-month project in which the students work in pairs to achieve the development, design, coding, construction, and demonstration of a microcontroller-base project of their own choice. The project culminates with a written report, an oral presentation, and a hands-on demonstration. Please refer to the course website http://www.me.sc.edu/courses/emch367 for samples of past projects.

The engineering students at the University of South Carolina, of which 22% are women and 30% are minority, are in need of support to expand and enhance the mechatronics/microcontroller education. The project currently undertaken with NSF support will empower the University of South Carolina engineering students with the knowledge and hands-on experience required for success in today's technologically competitive economy and market place.

2. Hardware for mechatronics/microcontroller education

The hardware issue is also challenging because of the large variety of microcontroller options available on the market. Our objective in developing this course has been to find a microcontroller that is widely used and accepted in the industry. Another criterion in our selection was to choose a microcontroller that has the essential functions that need to be conveyed to the students. The third selection criterion was cost, i.e., an inexpensive microcontroller. There are many microcontrollers available on the market today. However, none is better than the 68HC11 microcontroller for the classroom atmosphere. Many OTP microcontrollers may offer a better solution in a particular application, but their computer architectures and instruction set are not suitable to a general educational purpose. The 68HC11 offers a powerful and *easy-to-memorize* instruction set and has been around for more than 10 years. Once you have built your solid foundation of 68HC11 microcontroller expertise, you can easily apply your 68HC11 knowledge to the HC12 family or other microcontrollers in the future. Plus, there is a lot of application software that can be downloaded from the web. Therefore, the final choice was for the Motorola MC68HC11 microcontroller.

2.1. The microcontroller evaluation board (EVB)

For embedded applications, the microcontroller is usually used in single chip mode. In embedded applications, the microcontroller comes with the program already "burned" into its ROM memory. The user only has to place the microcontroller in its intended location, to power it up and initiate the program. Then, the microcontroller will run by itself. The storage of the program in ROM is done during the fabrication process.

For code development applications, the microcontroller must be used in connection with a host computer (PC) and/or a terminal. The programmer can develop the program on the host computer and then test it on the microcontroller. Alternatively, the programmer can develop the program directly on the microcontroller using the terminal interface. The electronic circuitry and IC chips associated with this process are placed on an evaluation board (EVB). The EVB contains expanded memory chips, a port replacement unit, as well as IC chips for servicing the connection to the host computer and/or a terminal. The EVB is essential for program development, since it allows the software programmer to develop and test the microcontroller application software. Once the microcontroller application software is developed and tested, then it will be "burned" into the ROM of the mass production microcontrollers. By using the EVB expanded system containing an MC68HC24 and a PC, the user can develop software intended for either single-chip mode or expanded mode microcontroller applications. Several microcontroller evaluation boards are commercially available. They range from the simplest to the most complex. For our lab, we have selected two types, one for code development (EVBplus2 microcontroller evaluation board from http://www.evbplus.com/), the other for embedded applications (Adapt11C24DX microcontroller evaluation board from Technological Arts, Inc. http://www.technologicalarts.com/myfiles/t1.html#EVBU).

2.1.1. EVBplus2 microcontroller evaluation board

The EVBplus2 microcontroller evaluation board from http://www.evbplus.com/ is a multifunctional product that incorporates several other features beyond the basic EVB functionality (Fig. 1). In addition to the microcontroller, port replacement unit, and expanded memory, it has a series of other components. These extra components are provided for facilitating the EVB use for classroom instruction, project development, and product design. As presented in Fig. 1, the EVBplus2 contains a conve-

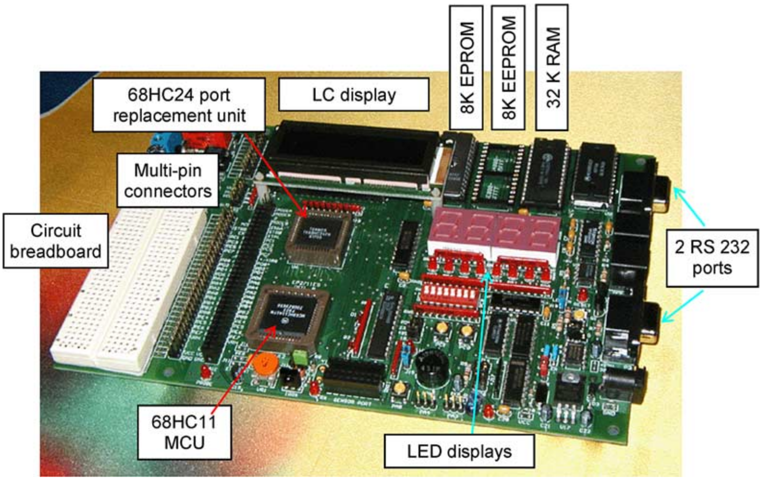

Fig. 1. EVBplus2 evaluation board for MC68HC11 microcontroller (http://www.evbplus.com/).

nient bread board for ad-hoc circuit design, a 4-digit 7-LED display, a row of 8 LED's for port B monitoring, a liquid crystal display, several port interfaces, and other features.

2.2. Adapt11C24DX microcontroller evaluation board

The Adapt11C24DX microcontroller evaluation board from Technological Arts, Inc. is characterized by its compactness (Fig. 2). On a 2.1-in. by 2.8-in. printed circuit board, this compact EVB accommodates the microcontroller (MCU), the port replacement unit, up to 32 kb of EEPROM and up to 28 Kbytes for RAM "piggy back" on the 32 kb EEPROM. It has a 50-pin connector that accommodates the

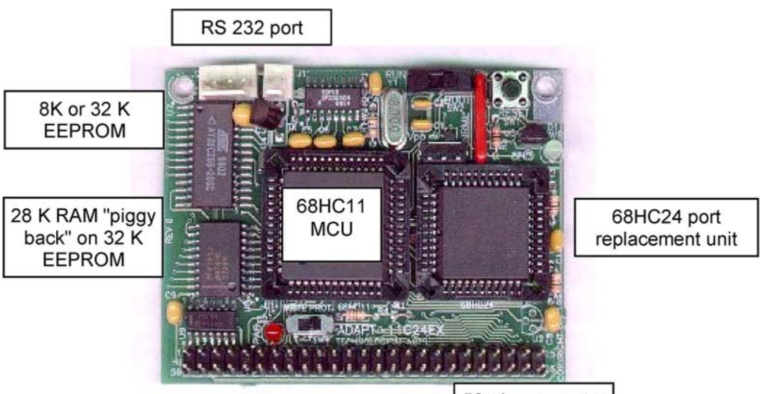

Fig. 2. Adapt11C24DX microcontroller evaluation board from Technological Arts, Inc. http://www.technologicalarts.com/myfiles/t1.html#EVBU.

microcontroller ports. Due to its compactness, it is also recommended for embedded applications in which expanded memory and the port replacement unit are required.

3. Software for mechatronics/microcontroller education

The software issue is particularly challenging since the mechanical engineering students do not receive instruction in script programming until they enter the microcontroller course. Today, most of the programming education of mechanical engineering students is done in visual languages such as MathCad and LabView, for which the College has site licenses. Hence, the teaching of a script language such as Assembly or C^{++} for programming the microcontroller has to done from basic principles. We found that the use of microcontroller simulation software greatly enhances the students' ability to climb this steep learning curve. We selected an inexpensive microcontroller simulation software based on the assembly language, THRSim11 by Harry Broeders, http://www.hc11.demon.nl/thrsim11/thrsim11.htm. This software appeared in the March 1999 DrDobbs Journal issue dedicated to simulation and emulation.

With the THRSim11 program, one can edit, assemble, simulate, and debug programs for the 68HC11 on one's windows PC. One can also use THRSim11 to debug the program on the target EVM or EVB compatible board. The simulator visualizes the CPU, ROM, RAM, and all memory mapped I/O ports (Fig. 3). It also simulates the on board peripherals such as

- timer (including pulse accumulator),
- analog to digital converter,
- parallel ports (including handshake),
- serial port,
- I/O pins (including analog and interrupt pins).

While debugging, the graphical user interface makes it possible to view and control every register (CPU registers and I/O registers), memory location (data, program, and stack), and pin of the simulated microcontroller. Even when the program is running! It is possible to stop the simulation at any combination of events. For example, stop when RxD becomes low and RAM location $003F contains $BD or I/O register TCNT is greater than $3456.

A number of (simulated) external components can be connected to the pins of the simulated 68HC11 while debugging. For example:

- LED's,
- switches,
- analog sliders (variable voltage potential),
- serial transmitter and receiver,
- many more... (see http://www.hc11.demon.nl/thrsim11/comp.htm).

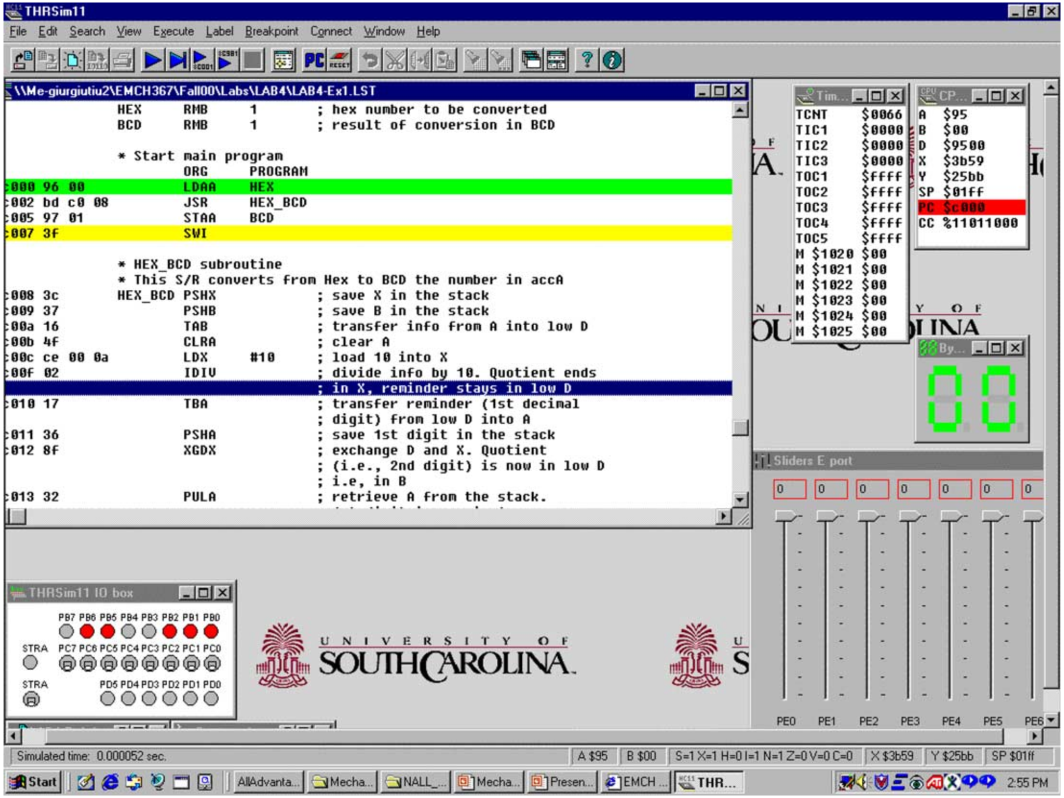

Fig. 3. Screen capture of the THRSim11 simulation and emulation software for MC68HC11 microcontroller. A site license was purchased for the University of South Carolina from http://www.hc11.demon.nl/thrsim11/thrsim11.htm. The site license includes the university logo.

There is also a 4×20 LCD character display mapped in the address space of the 68HC11.

THRSim11 can communicate with the Motorola EVM and EVB boards or with any other board running the BUFFALO monitor program. This monitor program can be downloaded (for free) from the Motorola website. When your assembly program is loaded into the target board the graphical user interface makes it possible to view and control every register (CPU registers and I/O registers) and memory location (data, program, and stack) of the real microcontroller. It is possible to stop the execution at any address and inspect or change the registers and memory.

4. Interfacing of mechatronics/microcontroller projects

Finally, we are addressing the interfacing between the microcontroller and the various electro-mechanical sensing and actuation components used in a mechatronics project. These issues are very important, especially with non-EE engineering students that have little or no previous experience with interfacing electronics with mechanical engineering hardware. We treated this aspect using a suite of functional modules. These functional modules are used for teaching hands-on skills related to the interfacing of mechanical, electrical, and electronic components of a mechatronics system.

Non-EE engineering students have the need for hands-on experience to increase their ability and confidence in tackling electrical and electronics concepts, especially during the realization phase of a mechatronics project. To address this need, we started developing a suite of functional teaching modules. These functional modules are intended as bolt-on building blocks with clearly defined inputs and outputs, and an explanation of the underlying operational principles. The students are expected to use the functional modules as a learning tool. After understanding their functionality, they are expected to duplicate the circuitry on their own breadboards to be incorporated into their mechatronics class projects, as well as into other hands-on projects, as appropriate. The modules that have been developed include:

(i) voltage divider,
(ii) op-amp signal amplifiers,
(iii) opto-electronic sensor,
(iv) on/off (field-effect MOSFET) power amplifier,
(v) linear power amplifier,
(vi) pulse-width modulation dc motor drive unit,
(vii) stepper motor drive unit,
(viii) AC/DC converter,
(ix) temperature sensor,
(x) humidity sensor,

(xi) H-bridge for DC motor (relay and transistor),
(xii) dimmer circuit,
(xiii) open collector buffer,
(xiv) voltage comparator,
(xv) limit switch,
(xvi) wireless transmitter and receiver,
(xvii) ultrasonic sensor.

Accompanying the functional modules are full reports containing electrical and component schematics, applicable equations, and a full experimental results during calibration tests results. These reports play an important role in the functional modules education. Several graduate students and undergraduate students composed these reports for every functional module when they first built these modules. The goals of these reports are helping the readers to understand the functional module circuits and facilitating reproduce the functional modules. The students are provided with a bag of components and asked to reproduce the functional module circuit following the circuit diagram and observing the physical realization in the functional module box. Using this approach, the students know what to expect when using the functional module by reading the report, and acquire the hands-on experience by building the physical object. As an example, Fig. 4 shows the appearance of the op-amp functional module. Figs. 5 and 6 show the circuit diagram of inverting and non-inverting op-amp which are presented in the functional module report. More details of the functional modules were presented by Giurgiutiu and Mouzon [9] and Giurgiutiu and Liu [8].

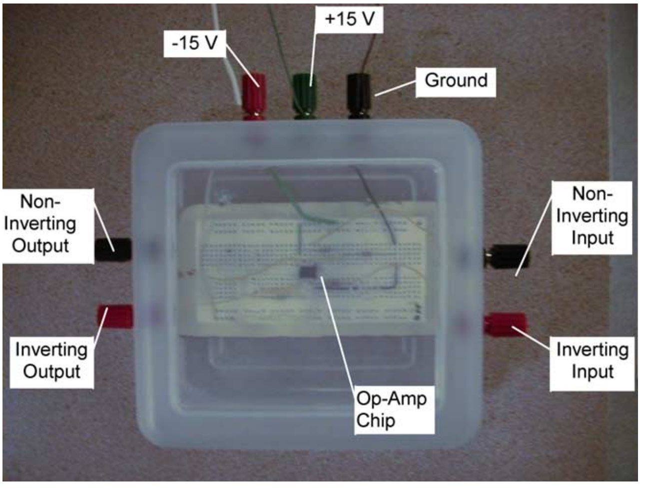

Fig. 4. Op-amp functional module displaying inputs and outputs for the inverting and non-inverting circuits.

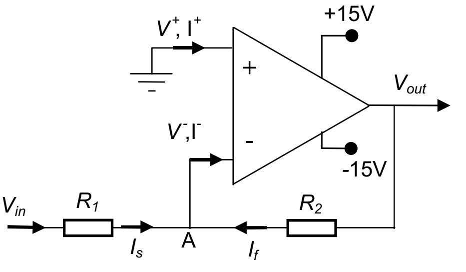

Fig. 5. Inverting op-amp circuit.

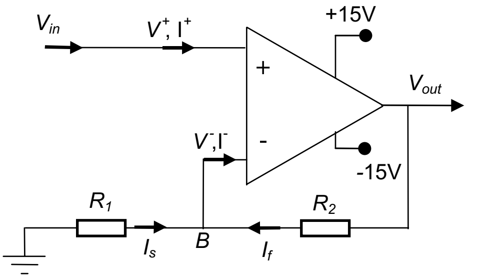

Fig. 6. Non-inverting op-amp circuit.

5. Conclusions

Many universities have started offering courses on mechatronics to undergraduate and graduate students. Such courses, cutting across departmental boundaries and combining theory, hands-on experiments, and technology applications, greatly benefit the undergraduate students, graduate students, and even faculty. They propel the curriculum towards the forefront of engineering education and directly answer the training and education challenges of the 3rd millennium.

The Department of Mechanical Engineering of the University of South Carolina has embarked upon a project to enhance the mechatronics education of non-EE engineering students. This project is funded by the NSF with cost-share from the Department of Mechanical Engineering and the College of Engineering and Information Technology. Our approach will help expand the students understand microcontrollers from both analysis and hands-on viewpoints. Our instruction has focused on using the microcontroller in various applications, rather then how the microcontroller is built inside. This is considered most applicable for mechanical engineering and other non-electrical engineering students.

The work on this project is continuing. Further developments will be reported in future publications.

Acknowledgement

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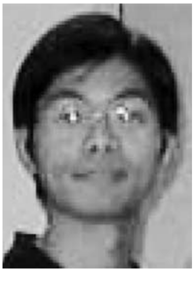

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