Curricular Review and Adoption of a Sophomore Level Microprocessor- Embedded Controller Sequence

Vance E. Poteat, John G. Adams
Merrimack College

Abstract

This paper describes curricular reviews that took place at Merrimack College during 2002, and the two-course sequence in the sophomore year created to address observed areas of concern. The Merrimack ECE Program is faced with unique challenges in that it is the only US undergraduate only program in a Catholic College. As part of the ECE department's Continuous Program Improvement mandated by ABET 2000, two curricular reviews took place in 2002: an internal review and an external Advisory Board review. Both reviews found a need for more hands-on lab work early in the curriculum, for more ECE courses in the first two years, and to eliminate a course in Statics. An upgraded curriculum was created, addressing these needs. The department's senior level course in microprocessors was reworked and became a fall, sophomore year class, and the Statics class was replaced with a spring, sophomore year Embedded Controller class including a strong lab component. Two more core ECE courses are now taken during the first two years, and significant hands-on experience is obtained in the Embedded Controller class. The Embedded Controller lab was created at low cost, using a freeware compiler and low-cost programming boards. This new sophomore sequence was presented at a meeting of the Advisory Board, which includes representatives from Lucent, Raytheon, and Analogic Devices among others, and was greeted enthusiastically as being aligned with industry needs. The first run of the Embedded Controller class was in spring of 2003, and received good reviews from students. Further advantages of the new sequence include: better preparation for possible co-op work in the junior year, more options in the Senior Design Project, ability to better understand routers and switches presented in Data Networking, and ability to take part in the measurement/control portion of departmental Power Quality and Energy Conservation research.

Curricular review at Merrimack College

The Merrimack College ECE department is unique in that it is the only ECE department in an undergraduate only Catholic College in the US: this presents the challenge that resources can be limited, and the opportunity that new ideas can be tried out without a lot of red tape. With this challenge and opportunity, the ECE department undertook curricular review as part of it's ABET mandated process of Continuous Program Improvement. A thorough review of the curriculum had not taken place since the early 1990s, leaving much room for change. Two curricular reviews took place: an internal review during the summer of 2002, and an external review in October 2002.

Internal Review

The internal review was conducted by the department's ABET committee which consisted of 5 full time professors in the ECE Department. Various places where the curriculum could be improved were identified, including:

- Not enough exposure to ECE classes during the first two years. Only five ECE classes total are required during the freshman and sophomore years, including the freshman digital sequence, the sophomore circuit sequence, and C for engineers.
- Too heavy a core ECE workload during the junior and senior years.
- A lack of hands-on experience during the first two years.
- A legacy Civil Engineering course in statics, which appeared to have outlived much of its usefulness. This class appears to have been added long ago in an attempt to address the ABET criteria: "Ability to function on a multi-disciplinary team," Criteria 3.(d).

After identifying the above opportunities for improvements, the team brainstormed on ways to address the above concerns. What emerged was to replace the existing senior level class in microprocessors with a fall, sophomore year class along the same lines, and then to follow up with a spring, sophomore year class in embedded controllers that emphasizes hands-on experience. Space in the curriculum for the second class would be created by eliminating the Civil Engineering class.

External Review

As part of its Continuous Program Improvement, the ECE department has created an advisory board (AB), composed primarily of practicing Electrical Engineers from local industry. Engineers with varying responsibilities, from one recent graduate working at Raytheon to a top manager in New England of Lucent technologies make up the 10-member board. Most AB members are Merrimack Alumni. An electronic technology department chair from a local community college also serves.

The AB met in October 2002 with members of Merrimack's ABET committee, and was asked the same question as the department asked itself: what are the strengths and weaknesses of the curriculum. The AB was not informed of the ABET committee's conclusions. The AB came to exactly the same conclusions as did the ABET committee: not enough ECE classes and hands-on experience during the first two years, too steep a jump in level of difficulty between the sophomore and junior years, and failure to see the importance of taking statics.

After evaluating the curriculum, the AB was then presented with the ABET committee's idea for a new sophomore microprocessor/embedded controller sequence. The AB was very enthusiastic about this sequence, concluding that it addressed all the abovementioned curricular weaknesses. Members felt that an understanding of embedded controllers is very much in line with industry needs, and that the increased hands-on would both make students better prepared to do co-op work and also would make better graduates.

The Two-Course Sequence

The embedded controller class was introduced in the Spring of '03, and the first full year of the sequence in 2003 - 2004. This section describes the contents of this sequence.

Today's computers fall into two major categories. The first category uses high performance microprocessors such as the Pentium® (x86) Class of Processors. The second category focuses on issues of space, cost, low power and fast development in products such as wireless phones, automobiles, security systems, and pagers. The two course sequence focuses on both categories starting with the Intel x86® Microprocessors (8088 – Pentium 4) and then on to one of the leading embedded microcomputers, the Intel 8051®.

Figure 1 - 8051 vs. x86

Item	8051	x86
Standard. Assembly Instructions		
- Arithmetic	24	19
- Logical	25	32
- Data Transfer	28	57
- Boolean	17	9
- Branching	17	58
Total	**111**	**175**
# of 8 bit registers	10	8
# of 16 bit registers	1	3
# of 32 bit registers	0	10
Min # of instructions for a loop	1	2
Min # of instructions for I/O	1	2
Short Jump Range	-128 to +127	-128 to +127
Standard Flags	O, P, C, I (x6), AC, 2 User	O, S, P, D, Z, C, I, AC
On-Chip Hardware	ALU, ROM, RAM, Timers (x2), Com Port, I/O (x32 bits)	ALU, L1 cache
Internal Data Bus	8 Bit	16 - 64 Bit

Unlike a high level language such as C, assembly language does not port across platforms but the underlining principles and techniques are the same. Once students learn one assembly language, they can usually learn another one very quickly. As an example, during the fall 2003 semester one author used and taught three different assembly languages. As shown in Figure 1, while the x86 has a more powerful instruction set and a wider data path, the 8051 has more built-in functionality and I/O. However, when looking at the details, they are overall quite similar. This allows the ECE student to learn a more powerful assembly language in the first course and another, similar, language in the second course while being able to spend more time on the hardware aspects of the embedded processor.

Introduction to Microprocessors (EE-226A)

The first of the two course sequence is based on the general purpose microprocessor and uses the standard IBM Personal Computer as the Hardware Platform. The hardware architecture is covered first and includes:

- Data Representation of Numbers in the IBM® Personal Computer (binary, Octal, Hex, Two's Complement, ASCII, and how to convert between them),
- Quick review of the standard Boolean functions (AND, OR, NAND, XOR, etc),
- General Intel Processor Architectures (8088 through the Pentium 4),
- General Operating Modes (Real and Protected),
- Memory and Addressing, and
- Standard Input / Output (keyboard, CRT, etc)

The software architecture and programming is then covered and takes up the rest of the course. This includes:

- Number representation (integers, real, characters, and strings),
- High level Assembly language basics (assemblers, linkers, directives, labels, etc),
- Instructions (Math, Data Transfer, Loops, Procedures, Conditional Processing, Stack, and Macros),
- Data Directives (storing and reading RAM, reading from ROM, etc), and
- High Level Constructs (such as IF, THEN, ELSE, and how they get transposed into assembly language).

The course consists of 3 hours of lecture and one 3 hour lab per week. The Irvine Textbook[1] is used and each copy comes with free assembly language software on CDROM. The book also provides instructors with Microsoft PowerPoint slides and an answer key. Prerequisites are one digital design course, EE-111A, and C/C++ for Electrical Engineers, EE-151A.

The course was offered for the first time during the Fall Semester of 2003. The students were comprised of sophomores and juniors and were all Electrical Computer Engineering Majors. The student feedback from the course was outstanding.

Embedded Controller Design (EE-227A)

The second of the two course sequence is based on a general purpose embedded single chip microcomputer and uses the Intel 8051® as the Hardware Platform. While there are many such devices to choose from including the Motorola 6811®, Microchip® 16X, and the Zilog Z8®, this part was selected because of its wide availability by so many different manufacturers. The entire development system including software is available for approximately $115. In addition, the 8051® parts only cost around $3 (quantity = 1). The hardware and software architectures are covered together and include:

- The Overall 8051 family of microcomputers,
- On-board ROM, RAM, Registers, Flags, Stack, and I/O,
- Assembly Language Instructions (Math, Bits, Routines, etc),
- Logic Programming (Compares, I/O bit programming, BCD and ASCII conversion, etc)
- Specialized built in Hardware (Timers, Counters, Serial Ports, etc),
- Built in Hardware interrupts,
- Interfacing to the outside world (buttons, A/D converters, Sensors, and Liquid Crystal Displays)

The course consists of 3 hours of lecture and one 3 hour lab per week. The Mazidi Textbook[2] is used and it provides a good roadmap along with good review questions and suggested laboratory exercises. The Hardware and Software development tools are from Rigel Corp[3]. Prerequisites are one digital design course, EE-111A, and Introduction to Microprocessors, EE-226A.

The course was offered for the first time during the Spring Semester of 2003. The students were comprised of sophomores, juniors, and seniors and were mixed Electrical Computer Engineering Majors and Computer Science Majors. The course also has a final project which is highly recommended. Each student, with instructor approval, picked what they wanted to do.

Experiences with the Sequence

The result from both of these courses was quite positive. In "Introduction to Microprocessors" (EE-226A) the students enjoyed learning about the internals of their own Personal Computer and how they could interact directly with the hardware using the Intel Assembly Programming Language. The most popular lab assignments were in the areas of generating color graphics and direct hardware interfacing.

In "Embedded Processor Design" (EE-227A) the students appreciated learning about the hardware / software interactions and tradeoffs. One of the first lab assignments was to program the processor to make several LEDS alternately flash on and off initially very slow and then extremely fast. The excitement within the lab was amazing as they learned how to both turn them on and off but also how to control the brightness by changing the duty cycle. This enthusiasm continued throughout the semester as they also learned how to interface to buttons, 7-segment displays, com ports (exactly like those built into PC Motherboards), and Liquid Crystal Displays. However, the most exciting part of the course were the final projects [4]. The creativity within each student really came out during this part of the course.

One example was the Christmas Music and Lights project. This student had an interest in music to start with and came up with an idea for a project related to his hobby. His 8051 circuit played "Jingle Bells" and flashed a series of LEDs in sync with the music. He programmed the on-board timers so his notes (C, C#, etc) would be accurate. Another project was the Digital Voltmeter. This student built a very simple resistor network with an Analog to Digital Converter and using an 8051 displayed the results on a 7-segment display. The other students had similar experiences.

One student who took the class last spring is enrolled in "Directed Study / Research" (CS-490A) in the Spring of 2004 and is using his "Embedded Processor" training. His focus is using embedded processors to monitor and control high power electronics (~100 Kilowatts) via a TCP/IP Ethernet connection. The results of this effort may possibly create an *energySTAR®* building by cleaning up the part of power system on campus. [5]

The early feedback from this course sequence is quite positive and student comments included:

"… I feel I benefited greatly from this class. I found it to be very rewarding; it has taught me a lot about consumer products. But it also uses a lot of what a computer would use. The final project was a good idea because it gave me an opportunity to make a real-world device and also show everything I learned throughout the class. This was one of the most rewarding and favorite classes I have taken"

"This course was very valuable to me. I got to see how the hardware aspects relate to the software development process. This is important since I am a CS major. The teacher did an excellent job explaining the material and did a good deal to help the students understand and share his enthusiasm for this type of combined hardware and software development."

"Now I see how the HW and SW work together"

"I love the hands on"

Conclusion

The Merrimack College ECE department has successfully engaged in the Continuous Program Improvement mandated by ABET 2000 by first engaging in internal and external curricular assessment, then adopting and implementing a very significant change in the curriculum. The sophomore level two course sequence is along the lines of those seen in other institutions, as is the favorable response of students. The fact that this sequence has been successfully implemented in the Merrimack ECE department with its unique challenges and resources is evidence that such an approach is valuable across a very broad range of programs.

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3. Hardware: R-51PB Programming Board: http://www.rigelcorp.com/r51pb.htm, Software: Reads51 Assembler/Simulator: http://www.rigelcorp.com/reads51.htm, Cost: Hardware: $115 each, Software: Free.

4. Partial list of the final projects: 16 Bit Four Function Calculator, Digital Voltmeter, Digital Thermometer, Game of Simon, Christmas Lights and Music, Digital Clock, and Encryption Dongle.
5. Ref: http://www.energystar.gov

VANCE POTEAT is a full-time Assistant Professor at Merrimack College teaching in both the Electrical Computer Engineering and Computer Science Departments. Prior to this, he worked at Bell Telephone Labs as both a Technical Manager and Distinguished Member of Technical Staff designing low power embedded products such as cordless phones. He holds 2 patents and has a BSEET from North Carolina at Charlotte and MSCS from Rutgers University.

JACK ADAMS is both Chair and a full-time Associate Professor in the Electrical Computer Engineering Department at Merrimack College. His research interests include curricular development, and also is a member of the Bioelectromagnetics Society with interests in the possible beneficial and detrimental health effects of non-ionizing EM fields. He holds MS and PhD degrees in ECE from the University of Massachusetts at Amherst.