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Dr. Panigrahi is a professor in the School of Engineering Technology at Purdue University, West Lafayette campus. He has 28 years of experience in teaching, research and administration. He has developed and taught courses in both engineering and engineering technology programs. Recently, he teaches courses related to applied computer vision and embedded systems in the Electrical and Computer Engineering Technology program. His research focuses on development and application of intelligent sensors and sensing systems for automation, inspection and quality control applications. He has special interests in graduate education and was the graduate coordinator of two different graduate programs at two universities. He has led the development of new graduate programs and has successfully supervised MS and Ph.D. students.He is a member of ASEE.

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Abstract:

With the increasing demand and emerging trend of IOT (Internet of Things) and Industry 4.0, the importance of embedded system is growing rapidly. This dynamic has made it imperative to redesign a course (junior level undergraduate) on embedded systems in the Electrical and Computer Engineering Technology program of the author's institution. This paper discusses how a systems-based approach was adopted to modify and develop new topics related to embedded systems over the last three years. For example, the transition process from 8-bit embedded platform to 32-bit along with required hardware and supporting software has been discussed. The design of new hands-on modular laboratory exercises and their implications on student learning has been presented. Team-based newly designed class projects emulated real-world solutions based on embedded systems. The class project also required the students to learn and apply project management skill (i.e. SCRUM). The experience and implications of these class projects have been reported with respect to the course learning outcomes. Lastly, the author's perspectives on how the course has prepared the students for the marketplace has been incorporated.

Introduction and Objective:

Embedded system technology is a key aspect of modern electronic systems and devices. Every Electrical Engineering Technology program (or similarly named) in the USA has at least one or two required course(s) in embedded system technology. In general, such courses are offered either at freshman, sophomore and/or junior level. They train the students with theory and application of embedded systems including how to program a given micro-controller and interface with different peripherals.

In the author's department, there is a sequence of two embedded system courses at the 1xxx and 2xxx level and they are required courses for the Electrical and Computer Engineering Technology (ECET) undergraduate program. At the time of writing this paper, the 2xxx level course used a popular microcontroller platform ATMEGA 2560. In addition, the author's ECET program also has another 3xxx level course "Advanced Embedded System". This course is designated as an elective in the ECET undergraduate program. Initially, the course was designed to use ATMEGA 2560 platform and focuses on training the students with RTOS (real-time operating system). This course is offered once a year, in the Spring semester.

In 2016 fall, there was an instructor change as a part of the routine faculty course allocation assignment and the author was assigned to teach this course in Spring 2017. A preliminary analysis was conducted to explore any modification or changes to the course material as part of the routine course improvement while keeping the overall scope of the course same. It was identified that with the popularization of Industry 4.0 and Manufacturing 4.0, it would be desirable to move from 8-bit microcontrollers to 32-bit microcontrollers at this advanced course level. This transition would be a smooth transition as the student already have gained prior experience in working with 8-bit microcontroller in its pre-requisite course (2xxx level) offered in the program while keeping the overall scope of the course same. The plan was shared with and approved by the curriculum committee members.

Thus, the author decided to redesign the course “Advanced Embedded System” offered in the author’s ECET (Electrical and Computer Engineering Technology) program.

This paper describes the modification of the course materials related to a 32-bit microcontroller along with its salient components.

Methodology

Overall Course Framework:

The course is offered as a three credit hours course (in semester system = 16 weeks) with two, 50-minute lectures and one, 110-minute laboratory. This course has a pre-requisite and the pre-requisite is a 2xxx level course related to embedded systems. This course is a technical elective in the program.

This revised course was offered in Spring 2017. It has been offered every spring since then. At the time of writing the paper, this paper has been offered three times. The enrollments of the course ranged from 11- 16.

This course primarily focused on building embedded systems concepts covered in prior perquisite class and emphasized on the application of embedded system. Hands-on laboratory experience was also part of the course to allow the students to apply and validate the concepts learned in the lectures. Moreover, the course also focused on reinforcing relevant foundational concepts of the embedded systems along with their different hardware architecture.

Table 1 illustrates the four learning objectives of the course and their associated Bloom’s taxonomy. To achieve these learning objectives, different active teaching and learning techniques along with modified conventional lectures and hands-on laboratory activities were used. In addition to the assignments, and two examinations (1 mid-term and 1 final), the class project was also important aspects of the class. Table 2 describes the grading criteria of the course.

A key thrust in the modification of the course material was to educate the students with the general design of the embedded system irrespective of any specific platform hardware along with the other foundational concepts. Then, it was planned to use a selected 32-bit microcontroller evaluation platform as an example platform for hands-on laboratory exercises. The main advantage of this concept was that students will be able to transfer their skills in design of embedded system irrespective of platforms. As the design of embedded system involves both the hardware and software, the design aspect covered both the segments.

Initially, after exhaustive search, a text book was found [1] and adopted for this course. The text book was published in 2008. However, it was not dependent on any platform. At the end of each chapter, the book contains nice review and thought questions corresponding to the salient section of the text in addition to the exercise problems. This feature was found to be very useful for easy cross-referencing. In the 1st year of the offer of the modified course, ATMEL studio 7.0 [11] was used. This option provided a continuity for the students as they used the same platform (or older version of Atmel Studio) in the prerequisite course.

The overall topics covered in the lecture included hardware, memory system, software modeling, the design and development of embedded system, analog input/output, Pulse-width-modulation, digital input/output, serial communication, wire-less communication, real-time kernels, operating systems, RTOS (real-time operating system), interrupts, timers, tasks, processes, safety, and reliability. Additional information and materials were provided from literature, and trade magazines. BeagleBone, the popular system-on-a-chip (SOC) system was also introduced [4,8,7]. In the initial two years, ATMEL ARM Cortex M0/M0+ processor (32-bit) platform was used as the platform for hands-on exercises (please refer to the following section on "Hands-on laboratory activities").

The instructor interacted with industrial representatives to assess their needs. Invited guest lectures came to the lecture or provided training. Moreover, the instructor kept up with the latest trend in the advancements of the embedded systems and associated technologies. The instructor also used the job advertisements related to embedded system engineer (or similarly named positions) to assess the needs and trends. The summary of the information was also shared among the students. This activity also helped the students to link the course materials and related skills to the market place demands. In the 2nd year, additional information related to the architecture for Cortex -Mo/Mo+ was added from the selected chapters of the book [3]. In the third year, it was decided to move to ARM Cortex M3 processor and related evaluation board. A new book [12] based on ARM Cortex M3 processor was introduced in addition to the foundational textbook [1]. Hardware and related architectural information of Cortex M3 processor was provided from the selected chapters from the book [2].

In addition, students also learned how to develop standardized documentation of the software developed for a given embedded system using the industry recognized platform, Doxygen [5].

Hands-on laboratory activities and class project: Laboratory activities (hands-on) were coupled with the subject matter learned form the lecture segment of the course. For the initial two years, SAM D20 Xplained Pro (containing Cortex M0) from ATMEL/Microchip company along with the peripheral boards (i.e. OLED1 Xplained pro, I/O Xplained Pro) were used for developing lab exercises. Atmel studio 7.0 was used as the accompanying software-development platform. In addition, Arduino ATMEGA 2560 was used as another platform for developing real-world application-based systems. In the 2nd year, another book [6] was used for conducting laboratory exercises. Additional activities also included the programming of

BeagleBone [8] using java script and sensors and subsequently connecting it to publicly available cloud platform.

In the 3rd year, new laboratory exercises based on Arm Cortex M3 [9] and the book [12] with a new operating system, Mbed [10], were developed/modified and used. The Mbed operating system was available online from the Arm's Mbed site [10]. The associated evaluation board LPC 1768 (NXP) was used [13]. The evaluation board was very compact and the foot-print is much smaller than that of ATMEGA 2560. The clock speed was also much higher. It can directly be connected to a computer via USB cable. The students found it easy to program the LPC 1768 board using Mbed. The hands-on exercises included the programming of the board to execute various operations including the LED control, the use of analog/digital input and output, Analog-to-digital conversion, motor control, use of different communication protocol, use of the LCD display unit etc.

Class Project: Class project was an integral part of this class. In one year, class project included the programming of BeagleBone platform along with the interface of selected sensor with the SAM D21 and ATMEGA 2560 board. In the 3rd year, a real-world environmental measurement system using selected sensors was developed by each team. Each team consisted of 3-4 people. The project involved agile project management method SCRUM [14]. This was designed to provide the students with the experience of using a popular agile project management method for developing an embedded system. The project activities involved working together in developing and testing the system, presenting their progress in a regular interval to the class, presenting the final system to the class and submitting a written project report.

Observed Impact: The instructor feels that the course revision was justified and was timely. The changes and modifications catered to the technological training needs of the students. The course also contributed for the students to get jobs related to embedded systems. This course was also helpful for the students who undertook senior capstone projects involving embedded systems or pursued higher study in the related technological areas.

Conclusion and Future Direction:

This redesign of the course was very time-demanding. However, it was timely and filled an existing gap in terms of the technical skill and training needs in the ECET program of the instructor's department. One of the challenges the instructor faced was on teaching the student on how to learn and program BeagleBone using Linux operating system. The instructor further streamlined the course without including the use of BeagleBone and Linux operating system. Continuous improvement is a requirement for any course. The instructor is currently working on how to include additional topic (i.e. security of the embedded systems) in the curriculum while maintaining the overall load and scope of the course. The instructor is also working on integrating different technological tools for incorporating additional active learning methods in this course.

Table 1: The learning objectives of the designed computer vision course and its associated Bloom's taxonomy.

Learning objective number	Learning objectives of the course	Bloom's taxonomy elements
1	Define, compare and contrast embedded systems terms and concepts including hard and soft real time.	Understand, Apply
2	Learn the process of designing and developing a generalized embedded system (from both hardware and software perspective).	Understand, Apply, create
3	Demonstrate the use of software modeling, design and documentation.	Understand, Apply, create
4	Learn and explain the concept real-time kernels, operating systems, real-time operating systems	Understand, Apply, Analyze
5	Demonstrate the use of application programming interface and programming language to develop and evaluate embedded systems for selected applications.	Understand, Apply, Evaluate, Create

Table 2: Grading criteria for the developed course.

Items	% of contribution to the course (total =100%)
Home works and quizzes	20
Midterm examination	15
Final examination	25
Laboratory activities and reports	25
Project	15

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