An Industry Related Project-Based Microcontroller Course

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Dr. Recayi "Reg" Pecen was formerly a professor and program chairs of Electrical Engineering Technology and Graduate (MS and Doctoral) Programs in the Department of Technology at the University of Northern Iowa (UNI). Dr. Pecen is currently serving as President and Professor at North American College in Houston, TX. He is also serving as a Chair of Energy Conservation and Conversion Division at American Society of Engineering Education (ASEE). Dr. Pecen holds a B.S in EE and an M.S. in Controls and Computer Engineering from the Istanbul Technical University, an M.S. in EE from the University of Colorado at Boulder, and a Ph.D. in Electrical Engineering from the University of Wyoming (UW, 1997). He served as a graduate assistant and faculty at UW, and South Dakota State University. He served on UNI Energy and Environment Council, College Diversity Committee, University Diversity Advisory Board, and Graduate College Diversity Task Force Committees. His research interests, grants, and more than 50 publications are in the areas of AC/DC Power System Interactions, distributed energy systems, power quality, and grid-connected renewable energy applications including solar and wind power systems. He is a senior member of IEEE, member of ASEE, Tau Beta Pi National Engineering Honor Society, and ATMAE. Dr. Pecen was recognized as an Honored Teacher/Researcher in "Who's Who among America's Teachers" in 2004-2009. Dr. Pecen is a recipient of 2010 Diversity Matters Award at the University of Northern Iowa for his efforts on promoting diversity and international education at UNI. He is also a recipient of 2011 UNI C.A.R.E Sustainability Award for the recognition of applied research and development of renewable energy applications at UNI and Iowa in general. Dr. Pecen established solar electric boat R & D center at UNI where dozens of students were given opportunities to design solar powered boats. UNI solar electric boat team with Dr. Pecen's supervision won two times a third place overall in World Championship on solar electric boating, an international competition promoting clean transportation technologies in US waters. He was recognized as an Advisor of the Year Award nominee among 8 other UNI faculty members in 2010-2011 academic year Leadership Award Ceremony. Dr. Pecen received a Milestone Award for outstanding mentoring of graduate students at UNI, and recognition from UNI Graduate College for acknowledging the milestone that has been achieved in successfully chairing ten or more graduate student culminating projects, theses, or dissertations, in 2011 and 2005.

He was also nominated for 2004 UNI Book and Supply Outstanding Teaching Award, March 2004, and nominated for 2006, and 2007 Russ Nielson Service Awards, UNI. Dr. Pecen is an Engineering Technology Editor of American Journal of Undergraduate Research (AJUR). He has been serving as a reviewer on the IEEE Transactions on Electronics Packaging Manufacturing since 2001. Dr. Pecen has served on ASEE Engineering Technology Division (ETD) in Annual ASEE Conferences as a reviewer, session moderator, and co-moderator since 2002. He served as a Chair-Elect on ASEE ECC Division in 2011. He also served as a program chair on ASEE ECCD in 2010. He is also serving on advisory boards of International Sustainable World Project Olympiad (isweep.org) and International Hydrogen Energy Congress. Dr. Pecen received a certificate of appreciation from IEEE Power Electronics Society in recognition of valuable contributions to the Solar Splash as 2011 and 2012 Event Coordinator. Dr. Pecen was formerly a board member of Iowa Alliance for Wind Innovation and Novel Development (www.iawind.org/board.php) and also represented UNI at Iowa Wind Energy Association (IWEA). Dr. Pecen taught Building Operator Certificate (BOC) classes for the Midwest Energy Efficiency Alliance (MEEA) since 2007 at Iowa, Kansas, Michigan, Illinois, Minnesota, and Missouri to promote energy efficiency in industrial and commercial environments.

Dr. Pecen was recognized by State of Iowa Senate on June 22, 2012 for his excellent service and contribution to state of Iowa for development of clean and renewable energy and promoting diversity and international education since 1998.

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Abstract

During the Fall 2011 semester, a project-based microcontroller course was developed and taught covering programming, microcontroller architecture, microprocessors, and design projects. This paper describes the project-based microcontroller course based on the Parallax Basic Stamp, a single-board computer that runs the Parallax PBASIC language interpreter in its microcontroller. There were five main reasons to choose a Parallax microprocessor: a) students in electronics program did not have, or were not required to take any programming background before taking this course; b) Parallax offered a variety of sensor units and related modules to conduct a variety of experiments and make projects as part of course purpose; c) the Parallax system is compatible with most of the commercial sensors and modules; d) freeware software and resources like books are available; and e) the cost of the system and parts. PBASIC was easier to learn when compared other programming languages such as C and Assembly. After covering fundamentals of microcontroller and programming algorithms, students were given a chance to learn PBASIC by writing programs to become familiar with the BASIC Stamp module and its programming environment. During 50% of the course time (other 50% percent is spent for coursework), students built five projects using a variety of sensors purchased from Parallax. Students were required to make at least five projects using the sensors and electronics components provided in the lab. These projects include but are not limited to: measuring (temperature, humidity, wind speed, sound, motion, and force); detecting (gas levels, smoke, the water level in the water tanks; building GPS units; development of mini-robots with sensors and other devices attached. All projects were tested in a campus environment to collect data and share the knowledge gained from the projects with other students. Students submitted reports for each project and demonstrated their projects at the end of the course period. Student feedbacks were compiled about the projects. All the details (course curriculum, student body, projects, and components) are shared in this paper.

Introduction

A microcontroller is the brain of an electronic device. Most electronic and electromechanical devices such as an alarm clock, cell phone, printer, digital watch, or game console come with an integrated microcontroller system. Microcontrollers manage interactions between the peripherals of a device according to the programming embedded in the memory section of the microcontroller [1-2]. In most cases, there are components such as analog to digital converters, displays, electronics components, sensors (tilt, position switch, gas, temperature, level, force, humidity, mass, distance, image, light, motion, etc.) that the programmer should be familiar with, in addition to understanding the working principals and functionality. In order to program a microcontroller, a programmer has to know the architecture of a microcontroller including its microprocessor, bus architecture, I/O system, memory type, interrupts, addresses, etc. It may be a challenge to teach students about all the types of the sensors, microcontroller architecture, and programming skills in a single course, especially for programs that offer only a limited number of courses due to cost of the labs and number of faculty members [3-4]. Moreover, in a single course, teaching programming language, microprocessor and microcontroller architectures,

laboratory experiments, and requiring projects may become an issue in terms of time in a three credit hour (2-2 format) class.

This project-based course is an application type course to familiarize students with the variety of sensors being used in industrial applications. The main objective of the project was initially to familiarize students with microcontroller programming and environment. Students were presented with the opportunity to conduct tests with a Basic Stamp Microcontroller, PBASIC compiler, and other interfacing devices. By using the Board of Education platform, along with a BS2 series controller, students learned the interfacing concepts for especially industrial applications. It concludes with an informal assessment of the project's success and preliminary ideas for related projects based on this experience [5-7].

The difference between this course and traditional microcontroller course is to use of variety of inexpensive sensors and electronics components available in the lab environments or easy to obtain. Some of the kits with pre-made boards are available in the market only allow or force students to use components embedded on the board comes with kit except Arduino). This sometimes limits the students to extend the projects unless kit comes with a breadboard installed on the main board. For the parallax boards it is easier to connect external components and have programming to recognize them. The Electronics program is offered under Industrial Technology department. The program is designated to offer more hands-on activities than a theoretical engineering degree requiring less math courses. Students are not only learning microcontroller programming but also getting familiarize with variety of sensor units are being used in industry. Students initially study the sensor units used in the projects and discuss/research potential applications. Then students investigate how to integrate sensor node to parallax kit for programming and testing environment.

Course Content

Electronics Technology students are introduced to Microcontroller architecture in a three-credit hour course consisting of two-hour lecture and a two-hour lab per week. The course is designed to initially introduce the basic concepts in microcontroller programming and interfacing followed by lab experiments which cover the advanced topics. Five projects are required from each student.

Description: This course introduces microprocessor architecture and microcomputer systems including memory and input/output interfacing. Topics include low-level language programming, bus architecture, I/O systems, memory systems, interrupts, and other related areas. The student will learn the functional and technological characteristics of microprocessor structures, memory components, peripheral support devices, and interface logic. Students will study various hardware configurations and interfacing techniques. They will also be involved in application-oriented laboratory experiments and design problems.

Objectives: Students who successfully complete this course are expected to meet the following course outcomes:
- Understand the general microprocessor and microcontroller architecture
- Describe the architecture and organization of a microcontroller

- Be able to write structured, well-commented, understandable programs in BS language
- Possess the skills to test and debug microcontroller programs in the laboratory
- Understand techniques for interfacing I/O devices to the microcontroller, including several specific standard I/O devices
- Discuss the differences between low level, mid-level, and high level languages
- Program the I/O ports for various process control applications
- Discuss the bus concepts, microcontroller hardware, and interfacing concepts

Hardware and Software

Usually, development tools needed for a microcontroller can be divided into two groups– software and hardware. Software tools include assemblers, program editors, compilers, debuggers, simulators, communication programs, and systems integration environment to implement applications. In order to download software through hardware a PC (or laptop) via a serial/parallel, a USB or internet connection is required. For the purpose of the course, students downloaded and installed freeware Parallax BASIC Stamp software [8]. The most basic setup requires at least a serial cable as is used in the BASIC STAMP or BASIC STAMP II from Parallax Inc. Software tools include text editors, cross assemblers, cross compilers, simulators, source level debuggers, and an integrated development environment. The text editor is a program that allows the user to enter and edit programs and text files. A simple editor can be a device such as Notepad or WordPad. However, for the microcontroller programmers, neither Notepad nor WordPad is appropriate because of their limited functions. Figure 1 shows a BS2 microcontrollers module and a development board [9-10].
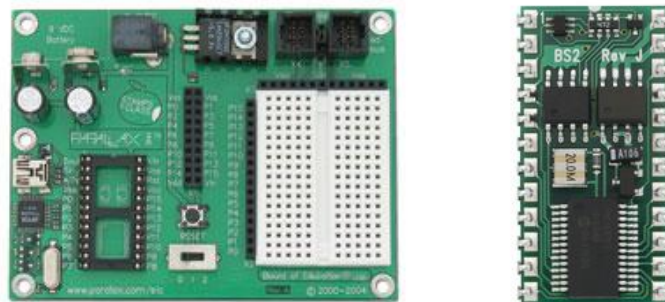

Figure 1. BASIC Stamp 2 Microcontroller Module and Board of Education Development Board

Course Exercises

Technology students (electronics major/minor) enrolled in this course had no background in a higher level programming language but were introduced to digital logic prior to this course. The students had no prior experience with microcontrollers, embedded systems, assembly language and interfacing, or computer architecture. The course began with an explanation of microcontroller architecture and the use of microcontrollers in industrial embedded systems. The programming process, assembly language programming, and use of development tools were also discussed. The students performed a sequence of assignments to learn about different features of the microcontroller and the instruction set. These assignments are listed in Table 1.

Table 1. Microcontroller Applications: Student Experiments

Experiments	Activities
Getting Started	Activity #1: Getting the Software Activity #2: Installing the Software Activity #3: Setting Up the Hardware and Testing the System Activity #4: First Program Activity #5: Looking Up Answers Activity #6: Introducing ASCII Code Activity #7: When You've Completed the First Program
Lights On – Lights Off	Activity #1: Building and Testing the LED Circuit Activity #2: On/Off Control with the BASIC Stamp Activity #3: Counting and Repeating Activity #4: Building and Testing a Second LED Circuit Activity #5: Using Current Direction to Control a Bi-Color LED
Digital Input – Pushbuttons	Activity #1: Testing a Pushbutton with an LED Circuit Activity #2: Reading a Pushbutton with the BASIC Stamp Activity #3: Pushbutton Control of an LED Circuit Activity #4: Two Pushbuttons Controlling Two LED Circuits Activity #5: Reaction Timer Test
Controlling Motion	Activity #1: Connecting and Testing the Servo Activity #2: Controlling Position with Your Computer Activity #3: Converting Position to Motion Activity #4: Pushbutton Controlled Servo
Measuring Rotation	Activity #1: Building and Testing the Potentiometer Circuit Activity #2: Measuring Resistance by Measuring Time Activity #3: Reading the Dial with the BASIC Stamp Activity #4: Controlling a Servo with a Potentiometer
Digital Display	Activity #1: Building and Testing the 7-Segment LED Display Activity #2: Controlling the 7-Segment LED Display Activity #3: Displaying Digits Activity #4: Displaying the Position of a Dial
Measuring Light	Activity #1: Building and Testing the Light Meter Activity #2: Graphing Light Measurements Activity #3: Tracking Light Events Activity #4: Simple Light Meter
Frequency and Sound	Activity #1: Building and Testing the Speaker Activity #2: Action Sounds Activity #3: Musical Notes and Simple Songs Activity #4: Microcontroller Music Activity #5: Cell Phone Ring Tones
Electronic Building Blocks	Activity #1: Control Current Flow with a Transistor Activity #2: Introducing the Digital Potentiometer
Prototyping Your Own Inventions	Activity #1: Building and Testing Each Pushbutton Circuit Activity #2: Building and Testing Each RC-Time Circuit Activity #3: Subsystem Integration Example Activity #4: Developing and Adding a Software Subsystem

All the lab exercises included the use of a Parallax BS2 board. Students were allowed to take all the modules and work at home. Students demonstrated their work to the instructor for each activity's grade. Students were asked questions about the activities during the demonstrations to make sure students understood coding and the purpose of the each component in the activity. This method was used to make sure the students understood the purpose of the activity and the functions of each component.

Course Projects

For the course projects, each group (two students) proposed five projects depending on the availability of the materials and parts in the lab. Students were provided list of the components available in the lab. A table of component list is provided in the appendix section (Appendix A). The Instructor provided a template for the students to record their project names for approval purposes. Each group proposed five projects on the template and submitted these for approval (Appendix B) before beginning their projects. At the end of the project implementation, students were required to write a one page report for each project they accomplished. The Instructor provided a template for the project reports (Appendix C). Table 2 shows projects names, components used, and cost of the materials for the project. What made the projects unique is students are free to pick projects in this course. They have access to use variety of sensors and electronics components to accomplish their projects. The electronics program is under industrial technology department targets to educate students at current industry standards. This course requires students to implement projects based on industry standards. For example using variety of sensors to measure humidity, temperature, pressure are the common applications to petrochemical, automation, manufacturing etc. industries to handle daily basis. Having to make an application, students are required to make investigations about specific industry needs and decide what the appropriate components to use are in order to determine the compatibility of the selected items.

Table 2. Microcontroller Applications Course Projects

Project	Status
Automatic disconnect buzzer to disconnect power	Complete
Distance calculator with music	Complete
Garage parking assistant	Complete
Model rail road traffic signal	Complete – Extended
Glass breaking alarm	Complete
Remote Controlled robot	Complete – Extended
A bi-color LED memory game	Complete
Security alarm system	Complete – Extended
Mini timer	Complete
Navigation of infrared headlights	Complete
A radar style display	Complete
Power supply	Complete – Extended
A mini robot for hazardous environment measurements	Complete
Navigation system with dual axis accelerometer	Complete
Ultrasonic module with digital display	Complete
Small object finder	Complete
Weather Station	Incomplete – In Progress
Digital clock	Complete
Game controller	Complete
A switch system to determine positions of the objects	Complete
Humidity sensor module	Complete
Sound impact sensor module	Complete

Motion detector with alarm	Complete
RFID System	Incomplete – In progress
Humidity and temperature sensor module	Complete
Anemomoter	Complete- Extended
Piezo film vibration application	Complete
Sound level measurement module	Complete
Tilt sensor module	Complete
Gas sensor module with alarm	Complete
Data Logger	Incomplete- Extended
Liquid level sensor module	Complete
Ultrasonic distance sensor module	Complete
Gas leakage sensor module	Complete
Noise level measurement sensor module	Complete
Solar Tracker	Incomplete – Extended
Motion detector sensor module	Complete
Color Sorter (for balls)	Complete
GPS systems	Incomplete – broken module – Ext.
Distance Sensor module	Complete
Automatic servo control module with joystick	Complete
Mini-robot (Autonomous control)	Complete

For each project, students created an algorithm before writing the codes and discussed this with the Instructor. Students also studied all the components (See Appendix A) used in their projects. For the issues faced to implement the projects, some of the groups made several phone calls to get more information about the specific component. Ten groups accomplished a total of fifty projects which were demonstrated to their classmates at the end of the semester. Some of the students wanted to continue with the same projects to extend them to an advanced level by adding more coding and components. These students were offered independent study (directed study) courses to extend their projects. Four of the students purchased their own kits and components to make hobby projects at home.

Student Feedbacks

Students were asked to write down their feedbacks about the class (lectures, activities, time provided, materials, presentations, and projects, etc.). Students were not provided a survey with questions; instead, they freely wrote their feedbacks. Student feedbacks were very positive. Written comments indicated that students did not feel constrained by time limitation in the class because of time spent in lectures, lab experiments, projects, or project demonstrations. The most common feedback was about the value of the projects to the course. Students enjoyed applying their gained knowledge to the projects and accomplished projects that similar to real industrial applications. A majority of the students liked the freedom and flexibility of using the Parallax Basic Stamp and determining their own projects. Students also commented that this course improved their learning experience and changed their ideas about electronics and industrial technology. They realized that most industrial systems have microcontroller controlled sensors, and that it is critical to apply appropriate programming. Students' positive feedbacks were reflected in their final grades. For the final grades, students earned the following (Table 3):

Table 3. Student Grades

Earned Grade	Number of students
A	16
B	4
C	1
D	1

General feedback is summarized as: 85% of the students preferred working with the Basic Stamp microcontroller because they could devote more time on design and development industrial type projects. Student also indicated that they prefer to take a more advance project based capstone course following this class to learn C and Assembly programming languages.

Conclusion

This paper presented brief course information about the project-based Microcontroller Application course offered to Electronics major/minor students in the Industrial Technology program. The objective was to offer a complete microcontroller course (mainly project-based) to introduce students to industrial systems based on microcontroller systems. This course is different from other traditional microcontroller courses because of the amount of time spent on applied course projects. Students commented that this course was difficult but learned about real life applications from these challenges, as well as how to overcome encountered issues. Allowing students to work at home by checking out complete kits received 100% positive feedback. Most of the students commented that they learned programming skills by completing the projects. The choice of development system (software, hardware, projects, and activities) can significantly impact the success of the course and the applicability of the course material to practical use in internships and postgraduate employment. For future applications, Instructor is working to make this course an online course which will allow students to buy their own kits and materials and take the course using Distance Learning.

References

[1] Gridling, G.; Weiss, B. "Introduction to Microcontrollers Courses", Vienna University of Technology, Institute of Computer Engineering, Embedded Computing Systems Group, February 26, 2007. Version 1.4. Retrieved on January 1, 2013 from http://paginas.fisica.uson.mx/horacio.munguia/aula_virtual/Recursos/Microcontroller_02.pdf

[2] Heinz, R. "Introduction to MicroProcessors and MicroControllers". Retrieved on December 28, 2012 from http://www2.fz-juelich.de/zel/datapool/page/160/MicroContr.PDF

[3] Yousef, A.; Dotson, E.; Nguyen, Phouc; Smith, C. "Parking Garage Using PIC Microcontroller", Proceedings of the 2008 American Society for Engineering Education Annual Conference & Exposition. AC 2008-119.

[4] Baig, M.; Islam, R. "Teaching PIC Microcontrollers to Under-Graduates in Electronics

Engineering Technology Program", Proceedings of the 2008 American Society for Engineering Education Annual Conference & Exposition . AC 2008-1211.

[5] Bolding, K.; Van Ess, D. "Upgrading A Microcontroller Systems Course With The Cypress Psoc", Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition. AC 2007-1475.

[6] Yousuf, A.; Lehman, W.; Venkatesha, M.; Huang, C.L. "Teaching PIC microcontroller in EET Program", Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition.

[7] Liu, Y.C. "Development System for Undergraduate Microprocessor Courses, The University of Texas at El Paso", Proceedings of the 1996 American Society for Engineering Education Annual Conference & Exposition.

[8] Parallax Basic Stamp. Retrieved on December 31, 2012 from
http://www.parallax.com/tabid/295/Default.aspx

[9] BASIC Stamp 2 Microcontroller Module. Retrieved on December 31, 2012 from
http://www.parallax.com/Store/Microcontrollers/BASICStampModules/tabid/134/CategoryID/9/List/0/SortField/0/Level/a/ProductID/1/Default.aspx

[10] Board of Education Development Board (USB). Retrieved on December 31, 2012 from
http://www.parallax.com/Store/Microcontrollers/BASICStampDevelopmentBoards/tabid/137/CategoryID/12/List/0/SortField/0/Level/a/ProductID/126/Default.aspx

Appendix A

Boe-Bot Robot Kit - Serial (with USB adapter and cable) – Full Kit
12V Power Inverter for CCFL - End of Life (CCFL missing)
2-Axis Joystick
4 Pack of Pings
4-Directional Tilt Sensor
5-Position Switch
BlinkM
C2H5OH (Alcohol / Benzine) Gas Sensor
C2H5OH (Alcohol / Benzine) Gas Sensor Module
CH4 (Methane) Gas Sensor
CH4 (Methane) Gas Sensor Module
CO (Carbon Monoxide) Gas Sensor
CO (Carbon Monoxide) Gas Sensor Module
CO2 (Carbon Dioxide) Gas Sensor
CO2 (Carbon Dioxide) Gas Sensor Module
ColorPAL
Digitarl Thermometer
eTape Liquid Level Sensor
External GPS Antenna (PMB-688)
FlexiForce Sensor Kit - 25 lbs
HS1101 Humidity Sensor
Infrared Receiver
Infrared Line Follower Kit
IR Transmitter Assembly Kit
Melexis 90217 Hall-Effect Sensor
Photoresistor - VT935G-B
Phototransistor
Piezo Film Vibra Tab Mass
PING))) Ultrasonic Distance Sensor
Sound Impact Sensor
TCS3200-DB Color Sensor
Transducer, Weatherproof
TSL1401 Linescan Imaging Sensor Daughterboard
TSL230R Light to Frequency Converter
VTI SCP1000 30-120 kPa Pressure Sensor
X-Band Motion Detector
NARO Servo
12V Geared Motor
12V Brushless Fan
Solar Cells
Parallel LCD
433 MHZ RF Transceiver
12V Stepper Motor
GPS Antenna
Relays
Piezo Speakers
Resistor Kit
Potentiometer Kit (including Digital Potentiometer AS5220-B10)
Capacitor Kit
LED Kit
7-Segment LEDs
Transistors including Phototransistors
Switches

Appendix B

<div align="center">

ITEC 4369 Microcontroller Applications
Project Approval Form

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Names: _____ & _____

Project/Application Name: _____

_____

Instructor Approval: _____

Project/Application Name: _____

_____

Instructor Approval: _____

Project/Application Name: _____

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Instructor Approval: _____

Project/Application Name: _____

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Instructor Approval: _____

Project/Application Name: _____

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Instructor Approval: _____

Project/Application Name: _____

_____

Instructor Approval: _____

Appendix C

ITEC 4369 Microcontroller Applications
Basic Stamp Class Projects Report

Names: _____ & _____

Project/Application Name: _____

Materials/Parts: _____

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Introduction: _____

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Project Objectives: _____

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Discussions and Conclusion: _____

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