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Transformation of an Introduction to Microcontroller Course

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Transformation of an Introduction to Microcontroller Course

Abstract

This paper outlines the curriculum changes made to a freshman introduction to microcontroller course in response to several outside factors including the overall reduction of credit hours available for a degree, the total number of credit hours available per course, and the various calls to move away from standard laboratory experiences in favor of more discovery based experiences. The course has undergone a transformation from a standard two hour lecture with a two hour laboratory experience each week to include an additional *arrange one contact hour* to the laboratory portion of the course. The additional time requires the students to work outside of their normally scheduled laboratory session in pairs to tackle bi-weekly challenges that go beyond the traditional laboratory activities. These challenges expand upon the concepts covered in the course and require the students to complete small or simplified versions of real-world problems. These outside activities take place in a dedicated laboratory that is also utilized by sophomore and junior students working on similar problems which can foster interaction between the various students. It is believed that this interaction can illustrate to the freshman students the types of things they will be doing during their future studies and help to retain the students in the program. This paper discusses the changes to the courses, the laboratory environment, and the actual challenges that the students complete.

Introduction

There has been explosion in the number of digital devices over the last 30 years [1]. Embedded microcontrollers are one of the popular choices utilized in these digital devices to provide the control and decision making possible. Everything from automobiles, robotics, household appliances, toys and games utilize microcontrollers or microprocessors. Understanding how these devices operate and the ability to implement them in designs is an important part of an undergraduate curriculum [2].

Teaching a course in microcontrollers is full of challenges and students don't always want to be patient and learn the basics. Mondragon and Becker-Gomez describe the biggest challenge to teaching a basic microcontroller course is keeping the students motivated and engaged - "Students want to create complex applications immediately and our job as educators is to keep them with their feet on the ground by providing guidance through all the steps required to accomplish the type of applications that they envision and are motivated to do" [3]. "Students need to learn to appreciate the level of effort required to blink a simple LED as a precursor to use gestures on a touchscreen such as those available in smartphones and tables" [3]. "The worst part is that they want to learn how to develop smartphone or tablet like applications right away, and turning on LEDs does not impress them anymore" [3].

In order to build student motivation and engage them in potential exciting project earlier, an additional hour has been added to a traditional microcontroller course which requires the students to work on small-scale, real world problems in a dedicated laboratory facility. These outside activities require the students to take the foundational information from their normal laboratory activities and then expand upon to create a real working system.

The additional time added to the laboratory portion of the course does not alter the total number of credit hours for the course as the course has multiple options for the laboratory component. The pattern for the laboratory portion of the course can be 2 hours, 3 hours, or 2 hours plus an additional 1 hour to be arranged. The additional hour is significant because it allows additional content to be explored that would otherwise not be covered in the course. The additional activities utilize real world hardware and allows the students to work on more open-ended projects and discover based outcomes like those called for in the Engage to Excel report to the President and other calls for curriculum transformation [4]. These modules or building blocks also allow the students to work on independent projects as well.

Background

From a historical perspective, microprocessor and microcontroller courses have been taught with assembly languages by concentrating mainly on the architecture and programming of these devices, with very little exposure to their practical applications [5]. Ibrahim proposed an approach based on using the microcontroller as a design tool, emphasizing its use in solving practical engineering problems [6]. More specifically, Ibrahim indicated that the focus should be placed on using the microcontroller as a tool to solve an engineering problem rather than focusing on the details of the microcontroller architecture or assembly language instructions [6].

A more modern approach to microcontroller education is to utilize a high-level language like the C programming language instead of assembly languages. The C language allows the user to focus on what must be done, not how is it done. In most cases, a prerequisite course in C is required. This is the approach followed for the course of interest here, and is also followed at other institutions. One such example is the University of Alabama when students begin the work towards microcontrollers through a C programming course – ECE 285 [7].

Taylor and Jackson describe a traditional progression where the first course in microcontrollers focuses on the language and the I/O interfacing with peripheral devices [7]. It is then assumed that these topics have been covered sufficiently so that advanced courses can build upon this information. Rosen and Carr also describe an approach to microcontrollers where lecture covers the I/O ports and control registers for simple parallel digital I/O ports, analog-to-digital converters, serial communications ports, simple delay loops, discussion of the timer modules and circuitry for timing, counting, and pulse width modulation for generating complex waveforms [1]. These lectures are followed by a set of laboratory exercises that demonstrate the concepts.

In the book Making Learning Whole, the author David Perkins provides a list of seven principles to create an integrated learning environment to transform education [8]. Of the seven principles, three are of key interest for this transformation: "Play the whole game", "Make the game worth playing", and "Play out of town" [8]. The essence of these steps is that a "junior version" of a larger design is a great tool for learning as it forces the students to participate in the entire process instead of following a fragmented approach. When designed properly, the junior version of the design should provide a heightened since of motivation for the students giving them extra incentive to put in the required effort. The last principle relates to providing examples that are similar in nature to the "real" problems that students will need to solve. The students must then take this information and apply it to a different problem.

As introduced in the previous paragraph, motivation plays a huge role in education. Deci et al. states the ability to stimulate interest in learning, valuing an education, and instilling confidence in their student's own capacities is critical in the educational process as this leads to an intrinsically motivated behavior where the students engage for their own sake, not because of an external motivation [9]. Deci et al. continues with this "*results in high-quality learning and conceptual understanding as well as enhanced personal growth*" [9].

Broberg, et al. conducted a research survey into the learning styles of engineering technology students. "The greatest difference found in learning-style preference is that engineering technology students prefer sensory learning over intuitive learning" [10]. The underlying theme from their research indicates that technology students typically prefer an active, hands-on approach. A survey carried out by Ibrahim indicated that students loved the idea of learning by doing as they learned a great deal about microcontrollers and their applications by solving real engineering problems [6].

The Transformation

Under the original version of the course, the students completed weekly laboratory experiments similar to the ones described by Taylor and Jackson [7] and Rosen and Carr [1]. Each laboratory session was approximately two hours in length and focused on basic understanding of that week's particular subject matter. Very little time was available to tackle real world problems. A brief description of the original 15 weekly laboratory activities is listed below:

1. Introduction to the development environment
2. Basic input and output operations
3. Digital interface circuits
4. Using standard input and output (STDIO) with microcontrollers
5. Introduction to flowcharts, decisions and control structures
6. Making decisions using loops
7. More control structures and time delays

8. Utilizing bitwise operators to control output operations and make decisions
9. Interfacing with serial liquid crystal displays
10. Creation of an MP3 player through interfacing with serial MP3 player modules
11. Interfacing with matrix keypads
12. Interfacing with analog circuits through analog to digital converts
13. Introduction to pulse width modulation
14. Using pulse width modulation to control tri-colored LEDs
15. Introduction to 3-wire interfacing

Under the transformed version of the course, the 15 weekly laboratory sessions have mostly remained unchanged. The major difference is that the students are now required to spend additional time in a dedicated laboratory environment working on real world problems that expand upon the foundational information. Under this model, the students are expected to complete an additional 8 laboratory "challenges" using real world hardware to create the systems. These challenges are outlined below:

1. Utilize a MOSFET driver board to control 12 volt automotive LED lights
2. Utilize a solid state AC relay to create a time controlled AC outlet
3. Utilize a set of solid state AC relays to create a light show with eight "vanity" lights
4. Utilize a graphical user interface to provide control commands to the microcontroller to create an automated recreational vehicle (RV) lighting system
5. Utilize a passive infrared (PIR) sensor to trigger a message playback using a serial interfaced MP3 player module
6. Create a keypad controlled solenoid lock for a cabinet/storage locker door
7. Utilize a wireless remote control module (key fob) to control exterior lights
8. Utilize the microcontroller to control a strip of tricolored LED lights to create custom colors and effects

The Hardware

One of the goals of this transformation was to rely on electronic modules that were manufactured and sold commercially instead of designing and building custom hardware. The biggest reason for this decision was that it would allow the students in the course the opportunity to acquire the exact same hardware and be able to build a replica of the real world hardware if desired. The students could also expand upon the hardware and create variations of the designs if desired. Utilizing commercially available products can also introduce the students to the various suppliers and foster their own creative energies to create their own custom solutions.

The first project (MOSFET control over vehicle lights) requires a set of MOSFET drivers to amplify the TTL level signals from the microcontroller and to provide enough current to drive the lights. This experiment leverages an existing automotive light system available to the students in the dedicated laboratory for these experiments. The automotive light systems where created with a golf cart light kit to save money and space. The MOSFET driver board is a product available from Sparkfun (www.sparkfun.com) item code DEV-10618 and includes six MOSFETs. The board is designed to be an Arduino compatible shield but has been built to serve as a general purpose board. An additional single channel MOSFET driver was also purchase from Sparkfun, item COM-12959, to bring the total number of MOSFET drivers to seven. A logic converter board was also purchased from Sparkfun, item BOB-12009, to allow the 12 volt signals from the turn signal switch and the brake switch to be converted down to the TTL levels required to properly interface with the microcontroller. The MOSFET driver boards and the logic converter board were mounted inside an enclosure with a clear lid so that the students could see the electronics located between their microcontroller development board and the actual lights.

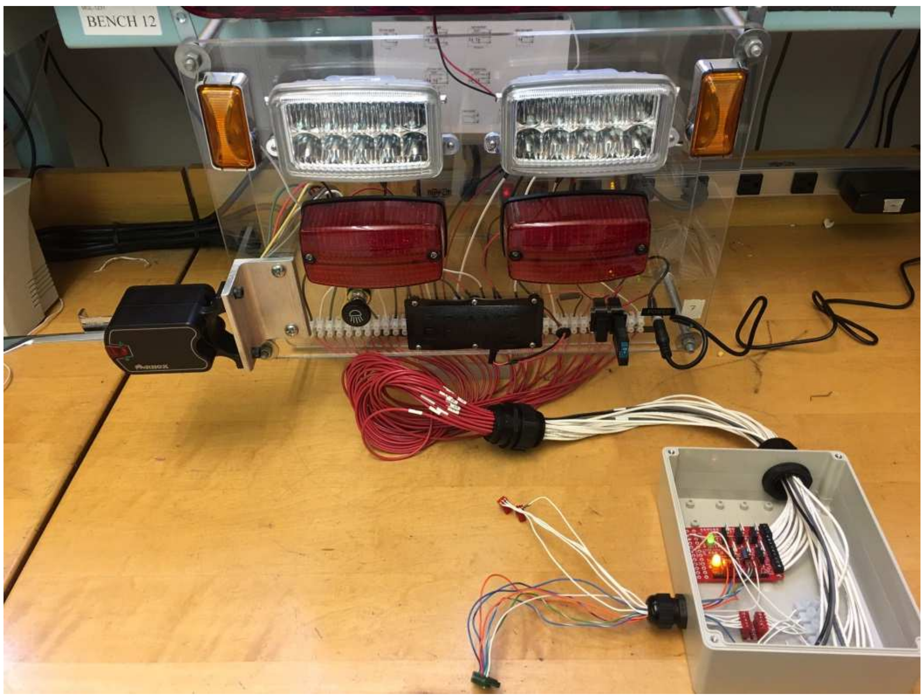

Figure 1 – Overall MOSFET Driver System

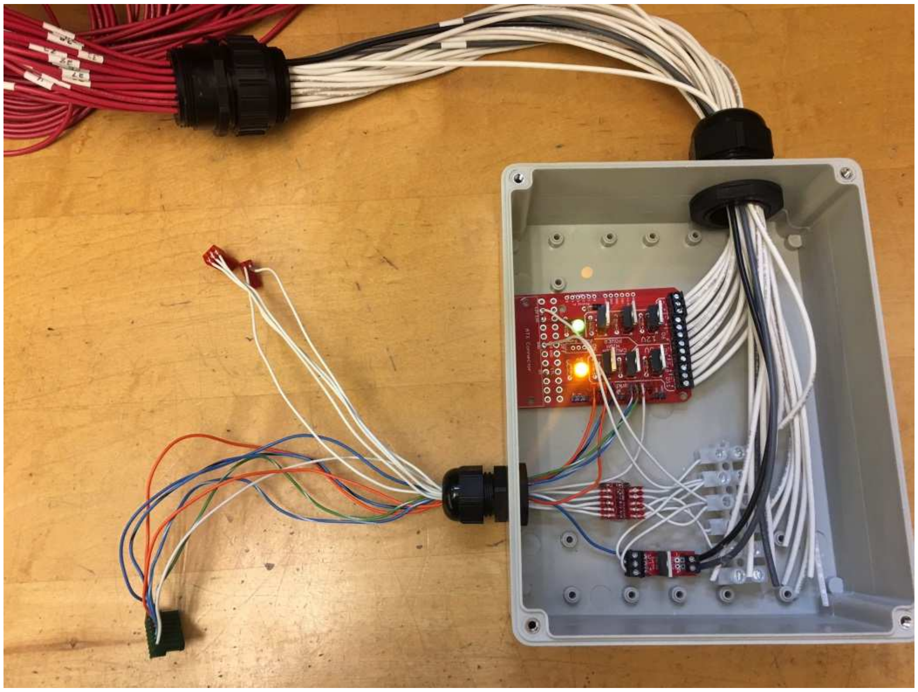

Figure 2 – Close-up of the MOSFET Driver System

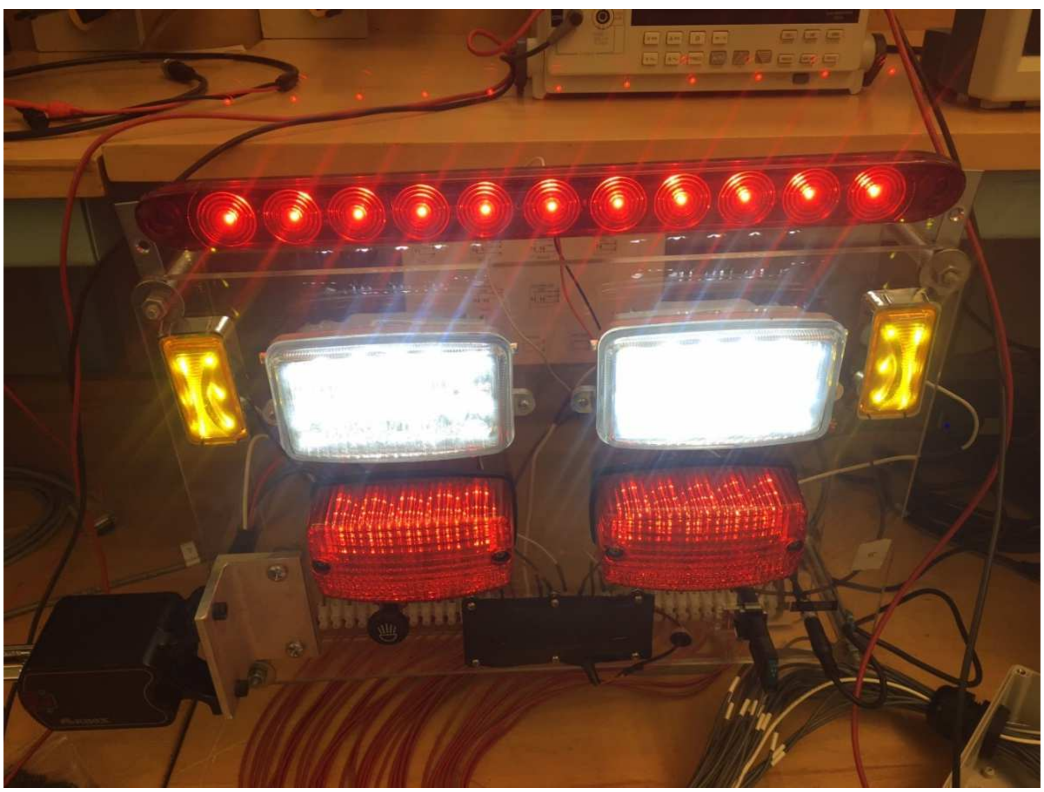

Figure 3 – Vehicle Lighting System

The first challenge will require the students to develop the software necessary to read the turn signal inputs along with the brake switch and then control the appropriate lights in response including flashing the center brake light in response to the brake being pressed. This system also forces the student to analyze the voltage and current requirements of the real hardware and explore driver circuits to amplify the current and voltage from the microcontroller as well as translate a higher voltage down to an appropriate value to interface with the microcontroller.

The next set of challenges utilizes solid state AC relays available from Sparkfun, item COM-13015. This relay is utilized as a single element to control a single AC outlet as shown in figure 4, and it is also combined with additional relays to create a bank of eight independently controlled outputs to control a vanity light similar to the one shown in figure 5, or in a bank of four to control wall mounted lights that could be installed in a house or an RV. This particular relay has one key advantage over some other solid state relays and that is the visual feedback provided by the red led that indicates when control power is being applied to the input of the relay. This feature allows the students to see that their microcontroller is in fact turning on a LED which is then controlling the rest of the circuit and ties directly with the challenges outlined by Mondragon and Becker-Gomez in the introduction of this paper – a simple task like turning on a LED can lead to exciting things happening.

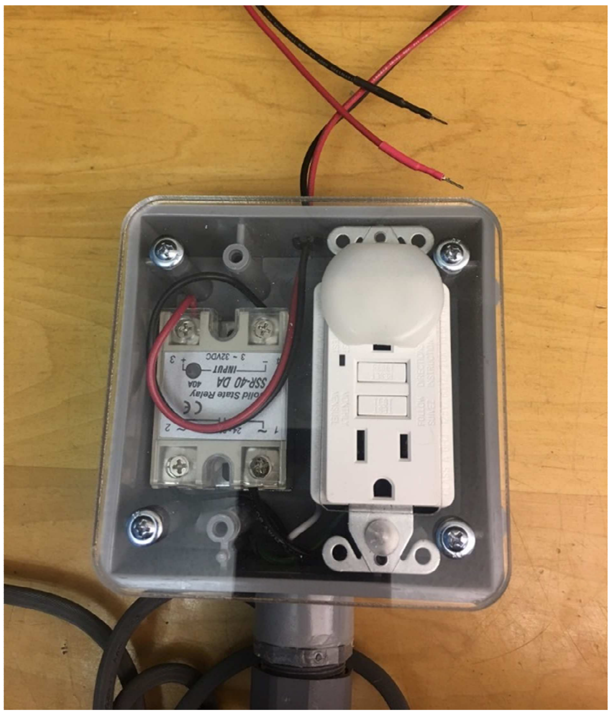

Figure 4 – Single AC Relay used to Control an AC Outlet

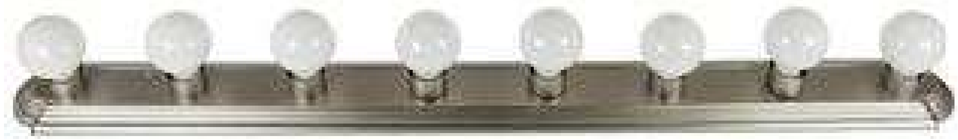

Figure 5 – Vanity Lights to be Controlled by AC Relays
Image retrieved from: www.sears.com

For the first AC relay challenge, the students will modify the code they created during their regular lab to turn on the AC relay at a certain time of the day and then turn the relay back off after a certain amount of time. This challenge will allow the students to create real world automatic timer circuits for a multitude of applications such security lights. The top performing students in the class could also expand upon the assignment to create random on and off times or other features to create the illusion that someone was home while on vacation or similar applications.

The set of eight relays and vanity lights allows the students to create various light patterns like those seen at a vendor display or trade show, or any other application. Giving the student this setup allows them the opportunity to really let their creativity flow. Although not a direct application, the students could even create the patterns typically associated with an emergency vehicle of police vehicle with the vanity lights.

The next challenge utilizes the graphical user interface (GUI) shown below with the same AC relays from the vanity lights project to create a custom home or recreational vehicle lighting system. In this challenge, the GUI running on a computer connected to the microcontroller development board. The GUI is designed to send simple serial commands to the microcontroller indicating which light to turn on or turn off. This challenge requires the students to process serial data and utilize bitwise operators to control the desired outputs. The GUI was designed to allow future expansion of the challenges which have not yet been implemented (controlling linear actuators).

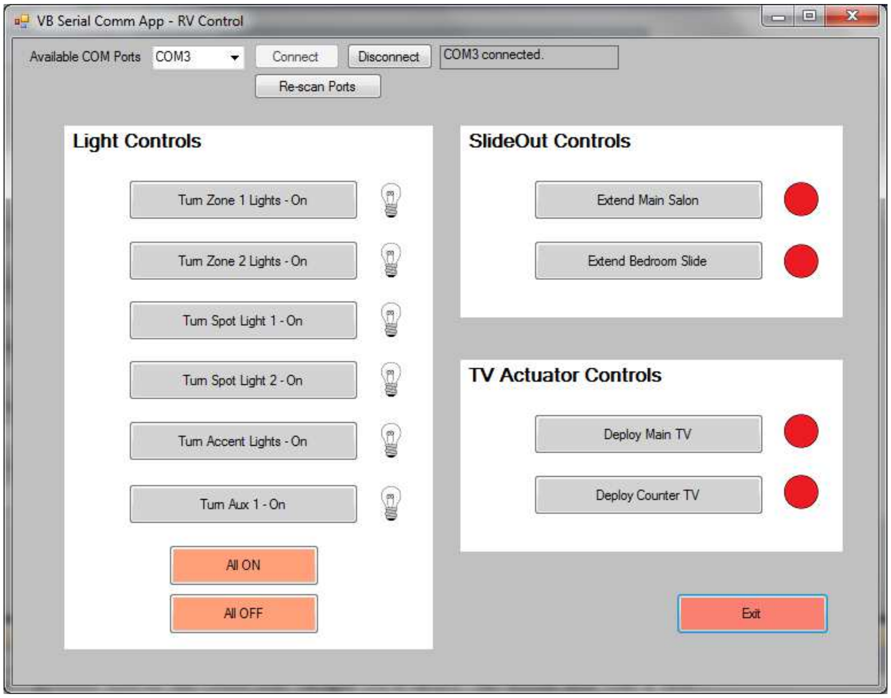

Figure 6 – Graphical User Interface to Control RV Lights

The next challenge utilizes a Rogue Robotics MP3 player shield available from Robot Shop (www.robotshop.com) item number RB-Rog-15 in conjunction with a passive infrared (PIR) sensor. In this challenge, the students will be required to read the output of the PIR sensor to trigger the microcontroller to play a sound track located on the SD card inserted into the MP3 player module. This challenge was originally designed to be completed during October where the students would play some sort of scary sound when a trick-or-treater approached. This basic idea can also be expanded into a multitude of other applications and serves as another opportunity to let the students be creative.

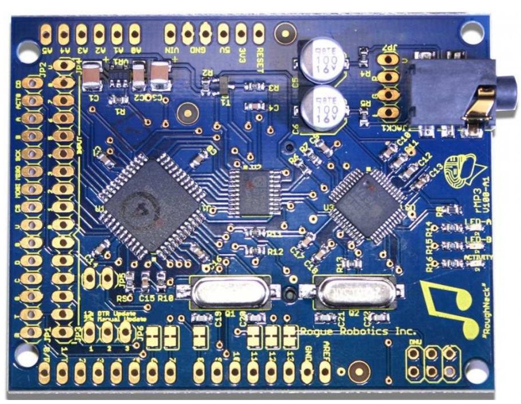

Figure 7 – MP3 Player Module
Imagine retrieved from: www.roguerobotics.com

The locking cabinet / storage locker takes advantage of the locking solenoid available from Adafruit (www.adafruit.com) item number 1512 shown in figure 8. In this challenge the students will expand upon their regular laboratory activity to create a digital combination lock using a matrix style keypad. Once the appropriate key sequence is entered, the microcontroller will output the control signal to operator the solenoid. Since the solenoid requires significantly more power than the microcontroller can supply, the same single MOSFET driver board from Sparkfun that was utilized in the first challenge is utilized again to interface with the solenoid. This repetition of driver circuits is intended to show the freshman students that these building blocks are applicable in a multitude of applications.

Figure 8 – Locking Solenoid from Adafruit
Image retrieved from: www.adafruit.com/products/1512

The wireless (key fob) control challenge utilizes the key fob remote control and receiver module available from Parallax (www.parallax.com) item number 700-10016. The remote control and receiver module allow the students to replace simple push button circuits that they have used in their normal laboratory experiments with a wireless option. The initial challenge is to pair this module with the same AC relay and AC outlet to control an outlet with the wireless remote. This activity, like the others, can easily be expanded upon by the students to control other applications such as the light pattern on the vanity lights.

Figure 9 – Parallax Key Fob Remote with Receiver
Image retrieved from: www.parallax.com/product/700-10016

The last of the current challenges requires the students to control a strip of tricolored LEDs. During their regular laboratory experiments the students utilize pulse width modulation to control a single tricolored LED. For the challenge, several strips of led lights are mounted in the dedicated laboratory. The strip lights simulate lights mounted under a cabinet such as in a kitchen, accent lights such as those found above cabinets or in a RV, and another other countless application. For this challenge the students have to determine which version of the light project they want to tackle and then replace the standard controller with their own microcontroller and MOSFET driver board. They can utilize the wireless remote key fob to control the light color, pattern, etc. They can also utilize the keypad to simulate a larger control panel if desired. This challenge requires the students to utilize their creativity and all the skills they have learned to demonstrate what they have learned.

Figure 10 – Example Tricolored LED Strip Lights
Imagine retrieved from: www.lightinthebox.com

Conclusions

This paper outlines a recent transformation of a freshman level introductory embedded microcontroller course. The transformation provides real-world examples of projects that can be implemented immediately in the course to engage the students into the learning environment. The systems allows the students to see that a simple task like turning on an LED can in fact have a much bigger impact like turning on the lights in a RV. Likewise, the students can see that a simple pulse-width modulated output signal can cause a string of led lights to glow in virtually any color and intensity. The additional challenges help to emphasis the need to study certain aspects of typical microcontroller applications and provide a multitude of possibilities to allow the students to engage in the creative process.

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