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One Last Tool for Their Toolbox: Preparing Students for Capstone Design

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One Last Tool for Their Toolbox: Preparing Students for Capstone Design

Introduction:

In many electrical engineering programs, students are required to demonstrate the success of their capstone design project by building and testing a prototype. Depending on the nature and complexity of the design specifications, the final product may be a composite of analog and digital, hardware and software, discrete components and off-the-shelf parts. The students are challenged not just by the design, but by the integration of these various types of technology. There are two ways we fail to prepare students to meet this challenge.

First of all, course work and laboratory work are compartmentalized. A student may take a digital electronics course with a complementary laboratory component. The lab experiences gained may be very suitable for demonstrating the analysis and design of combinational and sequential logic circuits, but they do not teach the students how to interface digital circuits with analog circuits or computer software.

Another way in which we fail to prepare students to meet the challenge of their capstone design project is by not providing enough experience in working with off-the-shelf parts and systems. A capstone project may require integration with a solar panel, motion sensor, or electronic keypad. But nowhere in the curriculum are students taught how to research parts, read data sheets, and verify operations, all necessary considerations before the design can progress.

To address these challenges, a series of open-ended laboratory experiences were designed for first-semester seniors. These experiences were designed to be completed in two weeks (including six hours of lab time). With only a basic understanding of the functionality, and perhaps a datasheet, the students spend the first week tinkering with a part or system that they have not used before. They must learn how it responds to various inputs and categorize each output. Between the first and the second week, the students then design a system to operate the part or system in some predetermined manner. In many cases the design is a composite of analog and digital, or hardware and software. The design is implemented and tested in the second week.

Five experiments are described in the following pages.

The Design of a Motion Activated Light Switch:

The objective of this laboratory experiment is to design a circuit to simulate the operation of a motion activated light switch. When the input switch is in the “on” position, the light is to be illuminated for 5 seconds. If no motion is detected from the motion sensor during this time, the light is to be turned off. If motion is detected, at any time, the light is to be illuminated for the 5 seconds following the detected motion. The light should be extinguished when the input switch is in the “off” position or if no motion has been detected in the previous 5 seconds.

The input switch is to be implemented using a DIP switch. The output light is to be implemented with an LED. The motion sensor input is to be implemented using the PIR Sensor Switch Module shown in Figure 1.

Figure 1: Seeedstudio Electronic Brick PIR Motion Sensor

Digital, analog, and computer solutions are possible.

The Design and Programming of a Vending Machine:

The objective of this laboratory experiment is to implement the input of a vending machine using the CH-926 multi-coin selector. See Figure 2. Meeting this objective will require calibrating the CH-926 to recognize U.S. coins and writing an HC12 assembly language program to keep track of the total dollar amount inputted and display this total on the LCD of a Freescale CSMB12 and PBMCUSLK Microcontroller Development System.

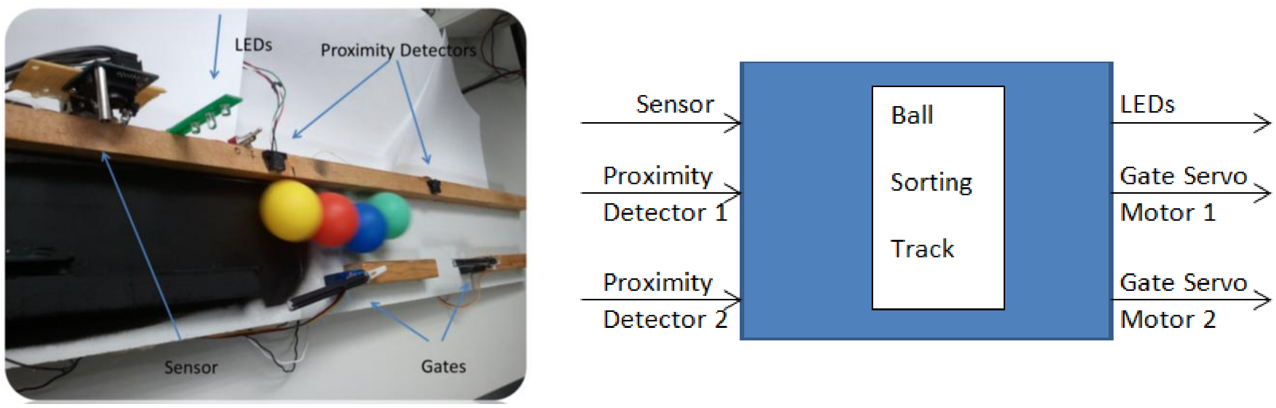
Figure 2: CH-926 coin sorter

During the first week of the experiment, the students worked to program, calibrate, and test the CH-926 to recognize U.S. quarters, dimes, nickels and pennies. Once programmed, the sorter would output the *programmed* number of pulses indicating the type of coin input. In between lab sessions, the students worked to write an assembly language program to calculate the total amount of money inserted into the coin sorter, and display this amount on the development board LCD.

Although the students were all required to create their solution in assembly language, they could choose the method by which they counted pulses. Solutions utilizing the HC12 on-chip resources, such as the pulse accumulator function and the input capture function, are possible. A less elegant solution is possible by monitoring the execution time of code.

The Design of a Ball Sorting System:

The objective of this experiment is to sort balls by color using several pieces of hardware that have been pre-assembled and mounted onto a track. See Figure 3.



a. Picture b. Block Diagram

Figure 3: Ball Sorting System

At the top of the track is a sensor capable of measuring the amount of red, green, and blue in the sensor field. Next to the sensor is a vertical array of LEDs. Further down the track are two swinging gates connected to separate servo motors. The servo motors are be operated to open and close the respective gates. Across from each gate is a proximity detector which can be used to detect objects that pass in front of the detector. Each piece of hardware is further described in the following paragraphs.

The sensor measures illumination and outputs a square wave for which the frequency is proportional to the strength of the illumination. The sensor is equipped with three filters (red, green, and blue, RGB) that allow the presence of these colors to be measured separately. The inputs S2 and S3 are digital inputs used to select the filter to be applied (S2S3=00 (red), 01 (blue), 11 (green)).

The RGB readings can be used to indicate the color of the sensed object. The result of this determination can also be displayed on the LEDs, driven with digital inputs.

Each gate arm moves as a function of the pulse width of the 50Hz signal applied to the corresponding servo motor. A pulse width of 1.5ms holds the arm in the closed position. A decrease in the width of the pulse will open the gate by a proportional amount. Likewise, an increase in the width of the pulse will close the gate by a proportional amount.

The output of the proximity detectors are open-collector, active-low signals, which may or may not represent logic levels.

In order to sort the balls in real time, it was necessary to detect the presence of a ball on the track, read the RGB values from the camera, determine the color of the ball, open the appropriate gate, wait for the ball to pass in front of the proximity detector opposite the open gate, and finally close the gate.

The students were only provided the information presented in this paper. No datasheets were provided for the various pieces of hardware. The students were expected to discover the functionality of each through experimentation.

The solution required knowledge of analog and digital circuit components as well as HC12 assembly language.

The Design of a Temperature Control System:

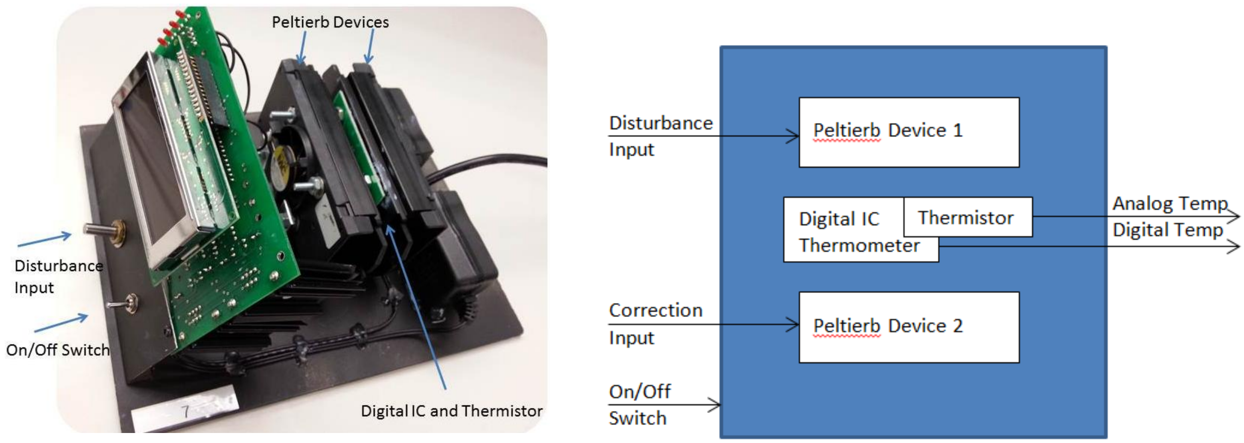
The objective of this experiment is to control the internal temperature of a small test chamber using several pieces of hardware that have been pre-assembled and mounted in the chamber. See Figure 4. The objective of this experiment is to use this hardware to measure the temperature in the test chamber and activate heating and cooling in order to maintain the temperature at $32 \pm 1^{\circ}$ C.

The PCB in the center of the test chamber is equipped with a digital thermometer, a thermistor, and a microcontroller. Students may select any of these three devices to acquire the test chamber temperature. Once acquired, the temperature is displayed on the chamber LCD.

- The DS1620 is a digital IC that outputs temperature readings via a serial interface. If this option is selected, the students must research the device and write a program to interface with the device in order to read the temperature.
- A thermistor is a type of resistor in which resistance varies with temperature. If this option is selected, through experimentation, the students must quantify the relationship between resistance and temperature and write a program to automate the conversion.
- The output from the microcontroller is a square wave with a pulse width proportional to the chamber temperature. The conversion rate is 10μs per 1° C. If this option is selected, the students must write a program to measure the pulse and automate the conversion.

The acquired temperature is displayed on the chamber LCD and used to determine whether the chamber must be heated or cooled in order to reach the target temperature of 32° C. The test chamber is equipped with a peltierb device which will cool or heat based on an input voltage, V_{in}. Students may select one of the following two methods to format V_{in}, thereby altering the temperature in the chamber.

- When the input voltage is less than 2.5V, the peltierb device will cool the chamber. Likewise when the input voltage is greater than 2.5V the peltierb device will heat the chamber. The rate at which the chamber is cooled or heated is proportional to the difference between V_{in} and 2.5V, $|2.5V-V_{in}|$.
- The peltierb device will heat or cool the chamber based on the pulse-width of V_{in}. For a digital input signal of 1 kHz, a signal with a duty cycle less than 50% will cool the chamber. Likewise a signal with a duty cycle greater than 50% will heat the chamber. Again the rate at which the chamber is cooled or heated is proportional to the change in duty cycle from 50%.



a. Picture b. Block Diagram

Figure 4: Temperature Control System Test Chamber

The test chamber is also equipped with a second peltierb device which will cool or heat based on the position of the disturbance input dial on the front panel. The overall temperature of the test chamber is a function of the temperature of both peltierb devices; therefore, this second peltierb device can be used to alter the chamber temperature testing the response of the student's system.

This was an interesting experiment because it introduced the students to new hardware and gave them the opportunity to select their own approach, digital or analog.

The Design of a Laser Tracking System:

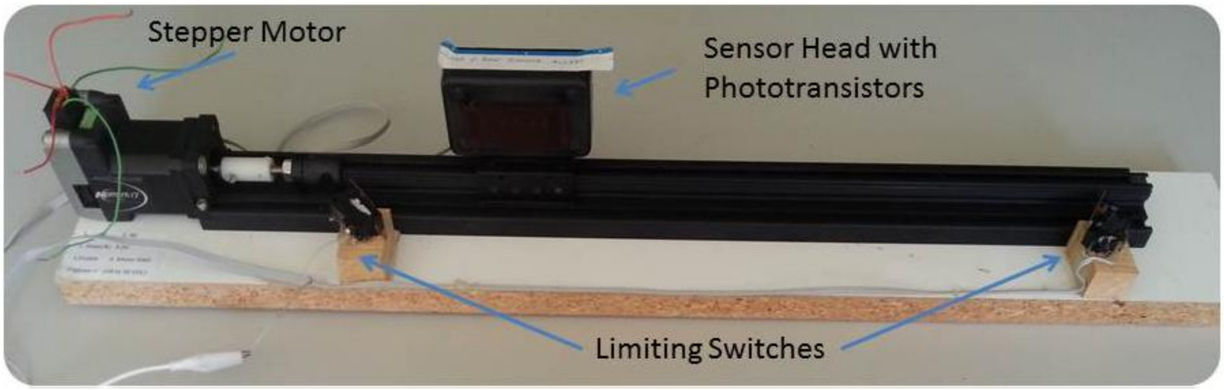
The objective of this experiment is to acquire and track a laser input using several pieces of hardware that have been pre-assembled and mounted onto a linear slide. See Figure 5.

Each laser tracking system contains a linear slide carrying a sensor head. The slide is powered by a stepper motor with a built-in driver. The DIR input to the motor controls the direction of movement (DIR=0 for left movement; DIR=1 for right movement). The STEP input, 40-50% duty cycle, is a pulse train that controls the speed.

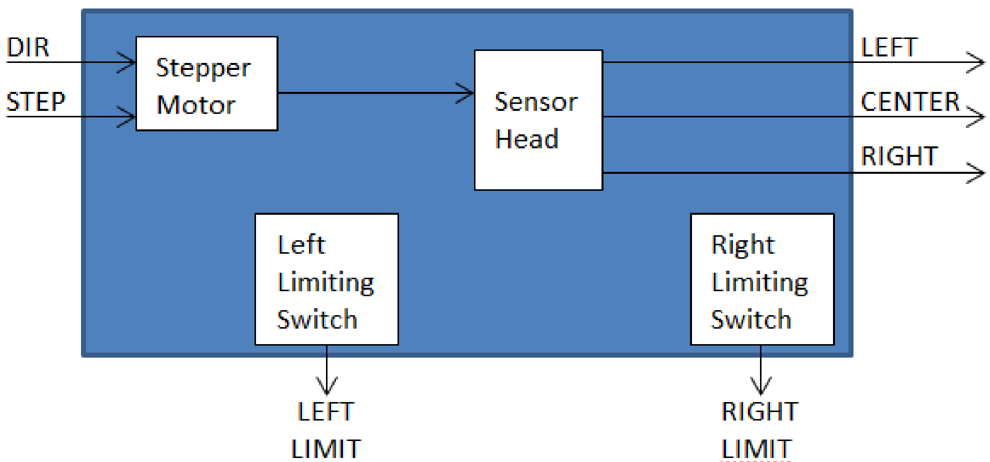
The sensor head consists of three phototransistors positioned 0.25" apart and vertically aligned with the laser. Based on the output of these three phototransistors, the direction of movement of the sensor head relative to the laser can be determined.

The slide carrying the sensor head has two switches located at both extremes. Activity at either of these switches indicates that the sensor head has reached the end of the slide. The DIR signal must then be toggled to prevent the slide from coming off the track.

In order to track a laser signal in real time the students must first acquire the laser signal. This can be accomplished by moving the sensor head back and forth until a signal is detected. Then the signal must be tracked. The presence of the three phototransistors make it possible to deduce the direction of the signal's movement. The sensor head must then mimic the movement of the signal, monitoring activity at the limiting switches.



a. Picture



b. Block Diagram

Figure 5: Laser Tracking System

The solution required knowledge of analog and digital circuit components as well as HC12 assembly language.

Assessment:

In addition to the general course evaluation form required by the university, an evaluation form specific to this course was administered at the end of each semester. Students were asked to provide feedback on specific experiments and provide general impressions of the course. Prior to 2012 these new experiments were assessed anecdotally and by asking the students about their favorite experiment.

The anecdotal evidence indicating the value of these new experiments can be seen in the following representative responses collected over the past three years:

- I enjoyed this lab A LOT more than any of the others, thanks!
- Best lab class I've taken at LMU!
- I think this was the most enjoyable class I had this semester, and I say this because it's cool seeing how electrical engineering really works in systems that are used in the world. Before this class I didn't see how electrical engineering really works in systems that are used in the work. Before this class I didn't see the real world connection, but now I do.
- If you don't enjoy this course, you are in the wrong major!
- Out of the three laboratory classes I've taken at LMU, this one was my favorite by far. I appreciate the hands on material and the building much more than just verifying theorems and circuit laws.
- An often difficult, overall fun class, that prepares one more for real work experience than any class so far.
- I'm glad I came to an institution with such a unique course because the skills I learned in this course, whether it be technical know-how or just patience, are invaluable skills that will make me a competitive player in the engineering job market.
- I feel that senior lab integrated all course material covered in past electrical engineering classes. I got to appreciate these materials more as I saw how the concepts, laws, or codes make a system work.
- Fun class. Got to play with a lot of toys.

In 2010, 62% of the students (8/13) reported that one of the new experiments was their favorite. In 2011 and 2012, 50% (7/14) and 60% (9/15) of the students, respectively, reported that one of the new experiments was the favorite. It was expected that this percentage would be much larger and would increase from year to year as the experiments were improved. This was not the case. After much consideration and reflection it was determined that surveying students about their favorite experiment is not an adequate measure of the effectiveness of these new experiments. In addition to being interesting and useful, these experiments challenge the students more than traditional experiments. Also of note, students with weak abilities in one or more technical areas showed a clear preference for more traditional experiments. The new experiments took them outside their comfort zone.

In 2012, two questions were added to the course evaluation intended to measure the effectiveness of the new experiments more accurately in preparing students for the capstone project. These questions are shown in Figure 6. Below each possible response, in blue, is the popularity of that response in a sample size of 14. Nearly all of the responses were positive (96%), with only one neutral response.

Conclusions:

Five open-ended laboratory experiences incorporating various technologies and off-the-shelf parts were designed to prepare students better to meet the challenges of the capstone design. The results of assessment indicate that these experiments are effective. This combined with anecdotal data show that the introduction of these new experiments makes the course more fun, more relevant to an engineering career, and better prepares students to meet the expectations of their senior project.

1. The prototype for your senior project next semester will undoubtedly include hardware and software. Several of the experiments were designed to give you experience interfacing hardware and software (2, 8 and 9). How effective do you think these experiments were in giving you this experience? Circle one of the following responses and explain your choice.

Very effective	Effective	Neither effective nor ineffective	Ineffective	Very ineffective
4/14	**9/14**	**1/14**	**0/14**	**0/14**

2. Your prototype will also undoubtedly include one or more off-the-shelf components. Several of these experiments (1, 8, 9) were designed to give you experience interfacing with off-the-shelf components (reading datasheets, tinkering with components in lab, interfacing components with additional hardware or software). How effective do you think these experiments were in giving you this experience? Circle one of the following responses and explain your choice.

Very effective	Effective	Neither effective nor ineffective	Ineffective	Very ineffective
5/14	**9/14**	**0/14**	**0/14**	**0/14**

Figure 6: Course Evaluation Survey Questions

Acknowledgements:

The ball sorting, temperature control, and laser tracking systems were designed and built by John Unalp at Loyola Marymount University. The Seeedstudio Electronic Brick PIR Motion Sensor was purchased from RobotShop.com. The CH-926 coin sorter is available from AliExpress.com