AC 2008-2552: INTERACTIVE SENSOR PACKAGE UNIT - A MULTIDISCIPLINARY DESIGN PROJECT

Yanfei Liu, Indiana University Purdue University, Fort Wayne (Eng)

Dr. Yanfei Liu received the B.S.E.E. Degree from Shandong Institute of Architecture and Engineering in July 1996. She then received the M.S.E.E. Degree from the Institute of Automation, Chinese Academy of Sciences in July 1999, and Ph.D. Degree from Clemson University in August 2004. She has been a member of the IPFW Department of Engineering since August 2005. Dr. Liu's research interests include robotics, dynamic manipulation, computer vision and image processing.

Jiaxin Zhao, Indiana University-Purdue University-Fort Wayne

Dr. Jiaxin Zhao is an Assistant Professor of Mechanical Engineering at Indiana University-Purdue University Fort Wayne. He received his BS from the University of Science and Technology of China, his MS from the University of Missouri-Rolla, and his PhD from Purdue University-West Lafayette. His research and teaching interests are tribology, machine design, solid mechanics and numerical methods including finite elements and parallel computing.

Interactive Sensor Package Unit – a Multidisciplinary Design Project

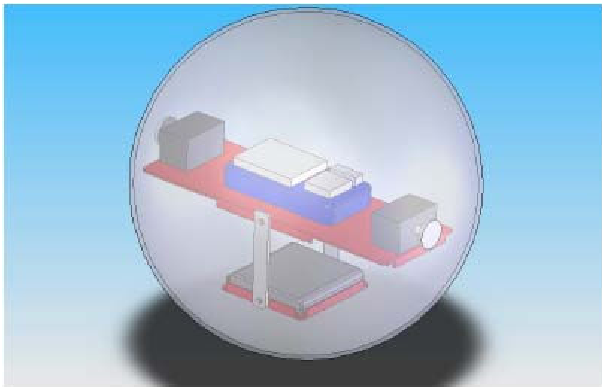
Abstract

This paper introduces a multidisciplinary capstone senior design project, which involves the design, build and test stages[1]. It is a two-semester project that was conducted by six senior students in the Department of Engineering at Indiana University – Purdue University Fort Wayne. The objective of this project is to design and build an interactive sensor package unit that can engage dogs into playing. The whole system design is composed of the shell, mobility mechanism, power source, control unit, sensor system, stimulator system and software. This paper also describes several different assessment approaches used throughout the project. The faculty members from the Department of Engineering and the local sponsors conduct the assessment. These assessments are based on either written reports or oral presentations.

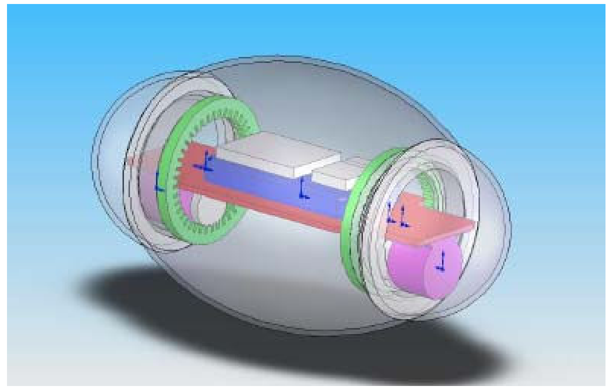
Introduction

There is a void area in the toy market for pets. No interactive devices that can autonomously engage pets in outdoor play exist. In order to fulfill the requirement of outdoor operation, the toy should also be waterproof for situations such as rain or falling into a pond. It also needs to be able to move over grass and slopes with a certain amount of incline. To fill this gap, a multidisciplinary senior design team in the Department of Engineering at Indiana University – Purdue University Fort Wayne (IPFW) designed and built an autonomous system that can be used as a development platform for devices that will engage dogs into playing. This is a two-semester multidisciplinary project[1] that was carried out by three electrical engineering students and three mechanical engineering students. In the fall of 2006, the students started with the formulation of the problem and then the generation of conceptual designs. After evaluating the conceptual designs, they completed a detailed design of the best conceptual design. In the spring of 2007, the students built the system and conducted the experimental testing.

There were a total of five conceptual designs generated[2]. The team evaluated these five conceptual designs based on the following criteria: ease of implementation, final manufacturing cost, mobility, reliability, ease of manufacture, dog appeal, etc. The two top-rated conceptual designs are illustrated in Figure 1. The conceptual design shown in (a) utilizes the principle of equilibrium to provide the unit's motion. The theory is that if a mass of substantial weight (the battery) is displaced from the center of the unit, the unit will move to regain equilibrium. The conceptual design shown in (b) utilizes motor driven gears that will rotate the shell of the elliptical unit. The equilibrium seeking conceptual design has the advantage over the dual geared motor design in the sense that it allows for rotation on all axes while the dual geared motor design doesn't. When the evaluation was performed, the equilibrium seeking unit ranked the highest in the critical criteria of ease of implementation, final manufacturing cost, and reliability.



(a) Equilibrium seeking



(b) Dual geared motors

Figure 1: Two top-rated conceptual designs

The final system was enclosed in a round 10-inch diameter shell. The size was selected based on the requirement that 99% of dogs should not be able to fit the unit in their mouths. The interactive unit should be capable of traveling through grass of nominal density at a minimum speed of 0.5 mph with a maximum speed of 5 mph. The unit should also be able to climb up a slope with a 5^{o} incline. The unit should also show some interactive features in order to engage dogs into playing. This means that it should be able to receive inputs from a microphone and accelerometers that are utilized to detect the action from the dog, e.g. whether the unit is being shaken by the dog, or if the dog is barking at the unit. The sound, light and motion output were adjusted based on the sensors' input to stimulate the dog. The whole system design is composed of the shell, mobility mechanism, power source, control unit, sensor system, stimulator system and software. Figure 2 illustrates an exploded view of the whole system. Figure 3 shows an image of the final built unit.

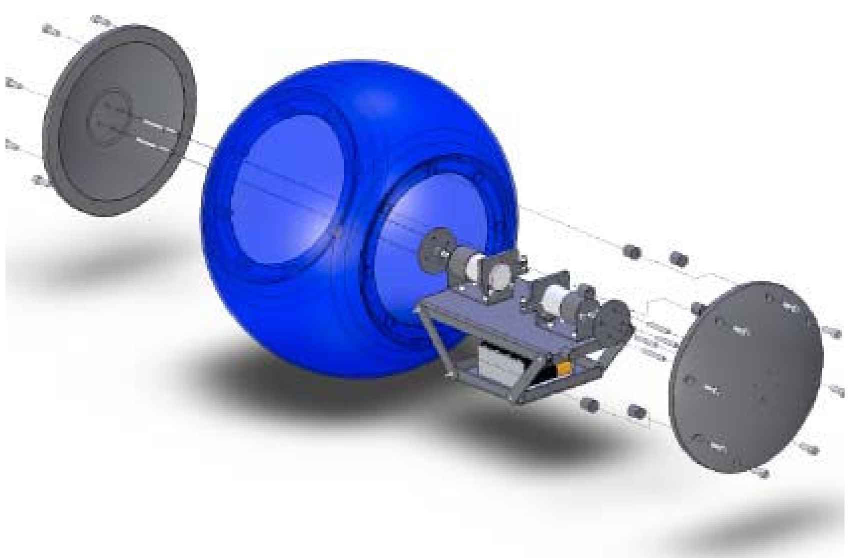


Figure 2: Exploded view of individual components for the unit


Figure 3: The actual unit

The remainder of this paper is organized as follows. We first present the mechanical and electrical design of this interactive sensor package unit (ISPU). Then we describe the assessment methods used in this project. Finally, we conclude the paper.

Mechanical design

The shell of the ISPU is composed of one mid shell and two end caps as seen in Figure 2 and 3. The mid shell was made of one type of non-transparent nylon, while the two end caps were made of clear acrylic plastic such that the pet can see the LEDs inside for the light stimulation. The end caps are designed so that the internal components are accessible. The mid shell is the main housing of the ISPU and protection of the internal electronic components. The internal components are in suspension inside the mid-shell and are connected to the two end caps only. There are grooves to insert O-rings between the mid-shell and end caps to prevent moisture/water from reaching the internal components so that the whole unit is water proof.

The internal components are illustrated in details in Figure 4. There are two DC motors mounted on top of each side of the mounting tray to drive the ISPU. The DC motor chosen for our system were Mabuchi RF-370 that has a gear ratio of 30:1. In order for the ISPU to be able to travel through grass of nominal density at a minimum speed of 0.5 mph with a maximum speed of 5mph, each motor would be required to provide a minimum torque of 3.75in-lb and a speed of 150 RPM. The Mabuchi motor chosen supplies 9 in-lb of no-load torque and has a no-load speed of 300 RPM. From the team's analysis, these motors will be capable of meeting the desired specifications[2].

Based on the system's design, the motor and its shafts support the entire mass of the internal components. A rear clamp that could be attached to the rear of the motor and bolted to the motor mount was designed to support the rear of the motor and ensure stability of the motors. The motors are then connected rigidly to the mounting tray by the motor mount with the rear clamp and are then connected to the mounting tray with eight 6-32 socket head cap screws.

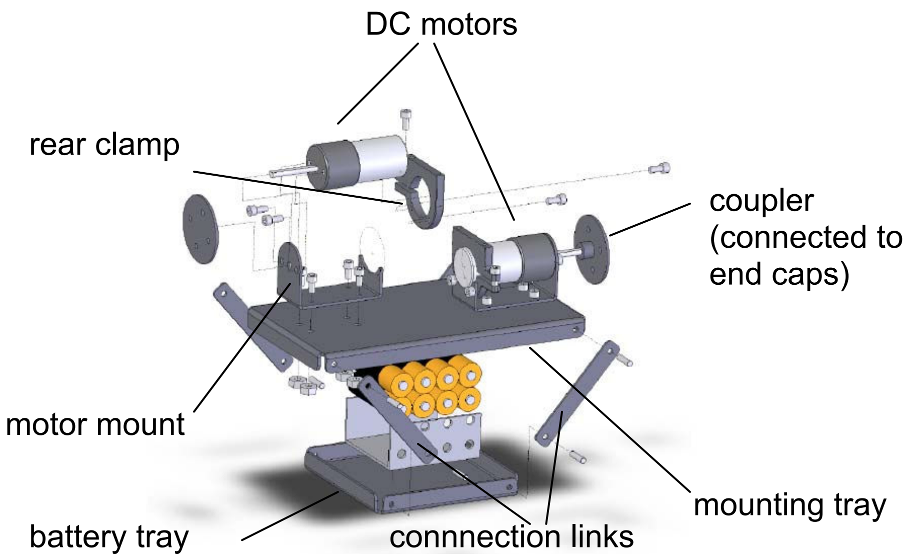


Figure 4: Internal components

The coupler shown in Figure 4 is what transfers the motors' torque to the ISPU's shell to provide rotation. The coupler is connected to the motors shaft by a 6-32 socket head set screw that connects the coupler rigidly to the shaft motor. Power is then transferred to the shell by four steel dowel pins (as seen in Figure 1) that are pressed into the end caps and slip through the coupler's four holes.

The mounting tray as shown in Figure 4 is the back bone to the ISPU's internal structure. It is made from 1020 HRS sheet metal and is 0.060" thick. It has holes for mounting the motor assemblies and for the links that connect the battery tray hanging below. It has been designed such that the PCB (printed circuit board) can be mounted to the underside for protection from the heat generated by the motors. The weight of the internal components will ensure that they would hang below the center of the ball all the time. Thus, as the motors spin, the shell rotates to keep the internal components from moving above the center of the ball.

Electrical design

The whole circuit design includes a microcontroller, sensor interfacing system, light stimulation system, digital RF remote control unit, and motor driving unit. The whole circuit including the motors is supplied by eight rechargeable Ni-MH batteries. The layout of a printed circuit board (PCB) was designed and the PCB was fabricated in the laboratory of Electrical and Computer Engineering Technology Department at IPFW. Figure 5 shows an image of the actual PCB. The PCB was mounted to the underside of the mounting tray shown in Figure 4 that has been described in the previous paragraph.

The operation of the ISPU is controlled by a microcontroller. The microcontroller senses sound via a microphone, and the units' motion via two accelerometers. Based on those inputs and pre-programmed algorithms the units' motors will be engaged and lights will be turned on and off. The microcontroller the team selected is Microchip PIC16F737. In the rest of this section we will briefly describe the light stimulation system, motor driving circuit, sensor interfacing system, and digital RF remote control unit.

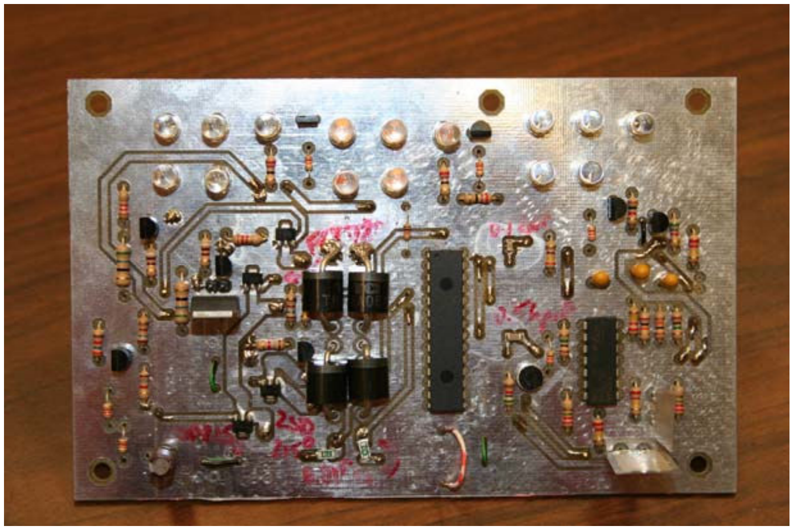


Figure 5: Printed circuit board (PCB)

The team initially carried out the project to design and build a toy for pets in general. That's when the idea of light stimulation came up because cats react well to light. Later because of the time constraints, the team decided on limiting the design only for dogs. However cats are very important potential "customers" for this toy. To make the design more generic to pets in general, the team decided to keep this feature. LEDs are used for light stimulation. The LEDs operates in an On/Off mode. In order to turn on and off the LEDs, transistor switches are used. The 2N2222A is chosen for the switching element. Figure 6 shows the LED circuit.

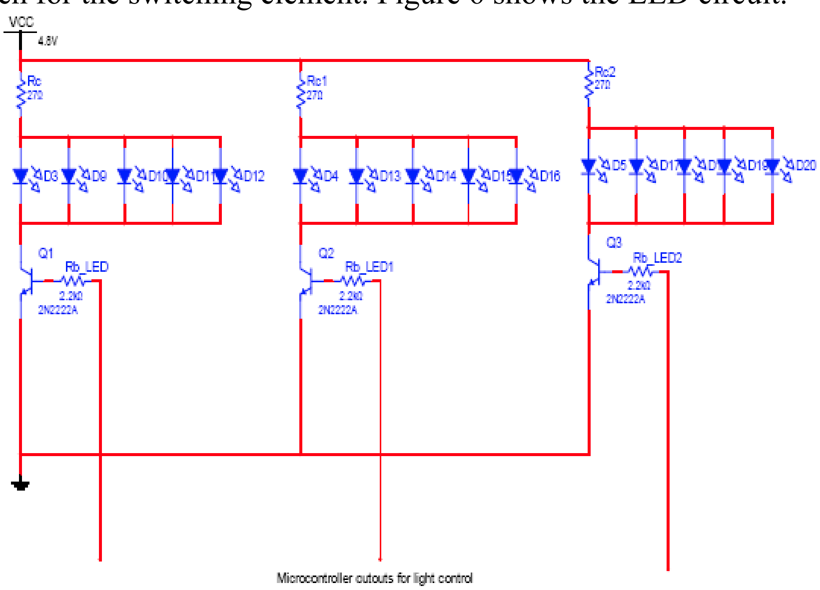


Figure 6: LED circuit

A standard H-bridge driving circuit is adopted for motor control. Based on the desired current of the selected motor, the value of all the circuit elements in the H-bridge circuit was calculated.

The H-bridge would allow for direction reversal. The motors are controlled by a PWM (pulse width modulation) signal from the microcontroller. A PWM signal is a standard way of controlling the speed of a DC motor. The motor speed is proportional to the duty cycle of the PWM signal. Figure 7 shows the H-bridge circuit.

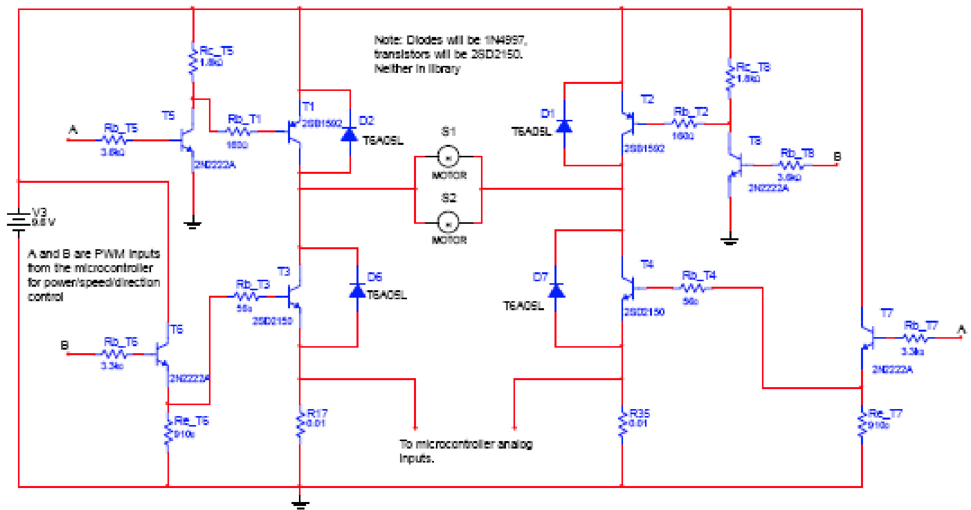


Figure 7: H-bridge circuit

Accelerometers are used to detect the sudden spikes in acceleration to judge if the unit is shaken by the dog or not and then take certain actions. The team selected LDT0-028K from MSI for its low cost and 50mv/g sensitivity. The signal provided from the accelerometers is relatively low and cannot be recognized by the microcontroller. Therefore an interfacing circuit between the accelerometers and the microcontroller is designed to amplify the signal. Figure 8 shows the circuit. The microphone is also used to sense the sound signal. The microphone circuit is very much the same structure as the accelerometers' circuit.

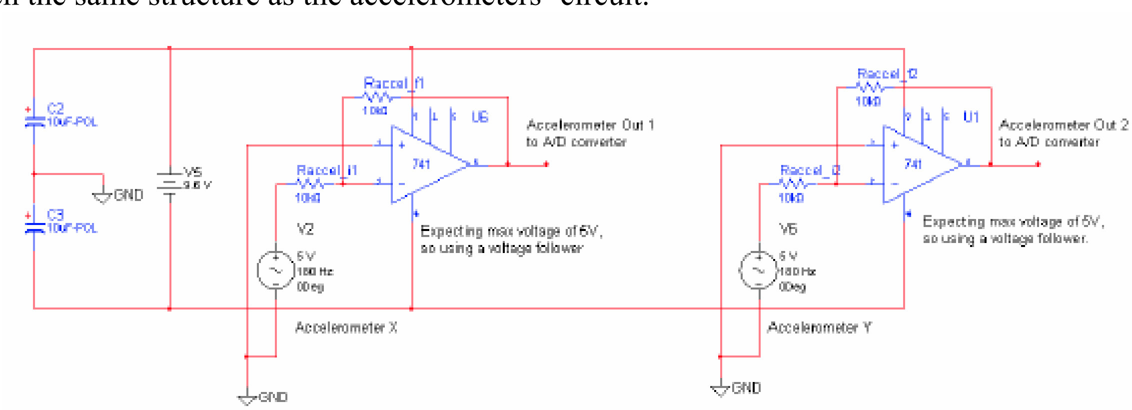


Figure 8: Accelerometer circuit

The digital RF remote control circuits provide signals with three different frequencies. These frequencies will be interpreted by the microcontroller as power on/off, activity level 1 and activity level 2. For different activity levels, the ISPU will move following a different preprogrammed routine. The remote control utilizes a 32kHz crystal oscillator. Figure 9 and 10 show the circuit diagrams for the RF remote control handheld unit and the receiver unit.

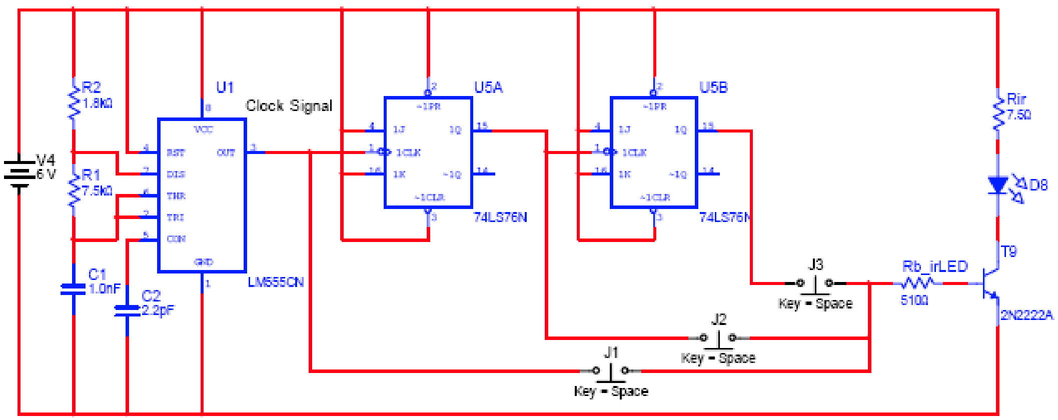


Figure 9: RF remote control handheld unit

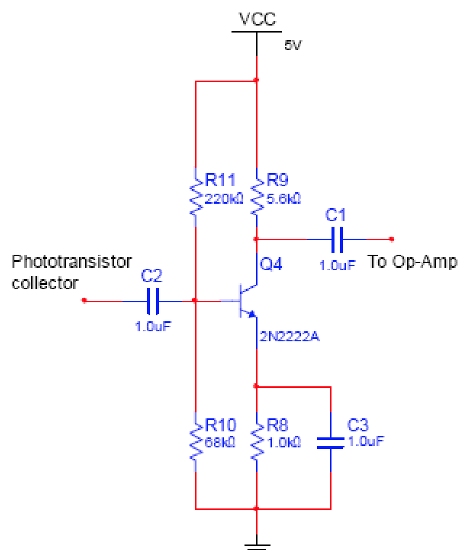


Figure 10: RF remote control receiver circuit

Testing Procedures and Results

Among many requirements for the sensor unit, the most important requirement is that the ISPU must be capable of traveling through grass of nominal density at a minimum speed of 0.5 mph with a maximum speed of 5 mph. The unit should also be able to climb up a slope with a 5^o incline. A program was downloaded into the ISPU that allowed the unit ramped into full power over the period of 5 seconds. The batteries were fully charged and the unit was taken outside to one of the grassy areas in IPFW campus. The unit was placed on the paved walkway, turned on and allowed to reach maximum speed before it encountered the grass. The unit ran autonomously during the testing. Results show that the unit is capable of traveling through the grass[3]. For the incline test, one of the inclined walkways on campus was utilized. The measurement shows that the incline degree of that walkway is $\sim 10^0$. Additionally an eight foot long piece of plywood was raised by 8.625 inches to create a 5^0 incline. The unit successfully climbed up in both situations.

Some other requirements were tested based on specific components involved. For the mechanical design part, the strength of the mounting plates was tested by attaching a strain gage on the plate (shown in Figure 11). The water resistant test (shown in Figure 12) was performed by running water over the sealing area with all of the internal electronic components removed and paper towels placed inside the unit. The paper towel stayed dry, which showed that the unit is water proof. For the electrical design part, the output for accelerometers and microphones were tested by capturing the output signal using a Tektronix TDS3032 two-channel digital oscilloscope. Results show that the signals are within the recognizable range of the microcontroller.

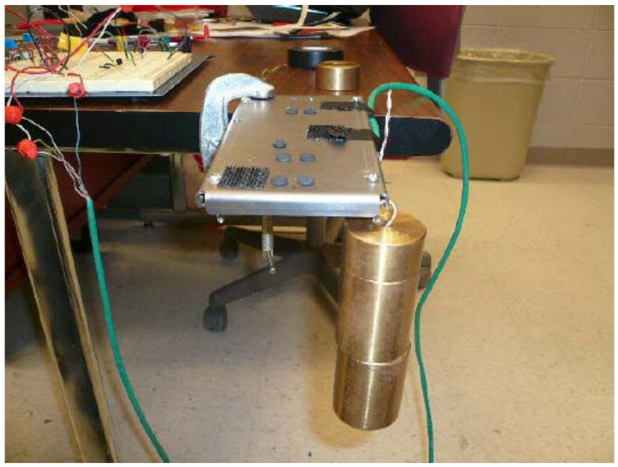


Figure 11: PCB torsion test

Figure 12: Water resistant test

Project assessment

As mentioned above, the senior design project in Department of Engineering at IPFW is a two-semester project[1]. In the first semester the students design the system. Then in the second semester the students build the system and conduct testing. In the end of each semester, the students will give an oral presentation about what they have accomplished throughout that semester. The presentation is open to the public. After the presentation, the faculty members from the department and the local sponsors will conduct the course outcome assessment for each individual project. The typical outcomes evaluated for the first semester capstone senior design course would be as follows:

1. The ability of the students to formulate a problem statement.

2. The ability of the students to generate solutions (conceptual designs) and evaluate them.
3. The ability of the students to obtain a final design including safety, economic and ethical considerations.
4. The ability of the students to communicate effectively.

In the end of the second semester, the similar assessment will be conducted by the faculty members from the department and the local sponsors. The typical outcomes for the second semester senior design course will be as follows:

1. The ability of the students to build their design.
2. The ability of the students to test their design.
3. The ability of the students to evaluate their design.
4. The ability of the students to communicate effectively.

There are also other assessment activities related to the capstone senior design project. Throughout the first semester, the project advisor(s) assess the problem statement, the generated conceptual designs, the evaluation of the conceptual designs, and the detailed final design. The assessment is based on the written reports provided by the team. Throughout the second semester, the project advisor(s) assess the measured parameters statement, building prototype, testing and evaluation, and the final design report. The measured parameters statement and the final design report are assessed based on the written reports provided by the team. The building prototype, testing and evaluation are assessed through the demonstration given by the team. In the end of each semester, the senior design course coordinator assess the ABET course outcomes a, c, d, e, and g [4].

Conclusions

In this paper, we present a multidisciplinary engineering capstone design project. The whole system design consists of the shell, mobility mechanism, power source, control unit, sensor system, stimulator system and software. We described the design of each component in detail in this paper. We also introduced the assessment methods used in the capstone design project. The project successfully delivered a prototype system that meets the requirement specified in the beginning. However at this time, the sponsor has decided not to continue this project.

Bibliography

1. Abu-Mulaweh, H., "*Engineering capstone senior design*", World Transactions on Engineering and Technology Education, Vol.5, No.1, pp. 153-157, 2006
2. Dimitrov, V.; Irish A.; Jones, C.; Kirk S.; Thomas, J. and Welter, D. "*Interactive Sensor Package Unit*," Capstone Senior Design Report, Department of Engineering, Indiana University – Purdue University Fort Wayne, Dec. 2006
3. Dimitrov, V.; Irish A.; Jones, C.; Kirk S.; Thomas, J. and Welter, D. "*Interactive Sensor Package Unit*," Capstone Senior Design Report, Department of Engineering, Indiana University – Purdue University Fort Wayne, April 2007
4. Engineering Accreditation Commission, "*Criteria for Accrediting Engineering Programs*," page 2, March 18, 2007.