Interdisciplinary Senior Design Project to Develop a Personal Blind Spot Information System

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Introduction

In recent years there has been a big push to get students into the STEM fields. However, what seems to be lacking in this academic push is the hands-on side of it. Engineering simply just is not about equations, but actually design and developing as well as fabricating a physical product. Something you can touch and, in most cases, see work. The Engineering Technology field fits into STEM academics and is very important. For companies to compete in the global marketplace, employers in the 21st century require their engineers couple the traditional engineering design skills with new skills in design and development, as well as the ability to function multi-disciplinary. With learning the importance of prototype development and manufacturing, the Senior Design team at Drexel University's Engineering Technology Department have decided to take on a challenge in operator safety which is paramount in any industrial environment, and the Personal Blind Spot Information System (P.B.S.I.S) has been designed to reduce the risk of injuries on the job. The easy to use system incorporates a heads-up display (HUD) controlled by a machine vision camera and microcontroller. The camera detects objects of interests, whether they be potentially hazardous vehicles or expensive company assets, that are labeled by a color-coded tag. The system is an attachment that has been designed to fit comfortably on standard hard hat models. The major goal of this project is to offer customers a turnkey solution for operator safety. The main educational goals of the project is for the team of students to (1) identify an engineering problem to solve; an engineering challenge, a new or novel idea; (2) develop an optimal solution for the problem in terms of cost and engineering constraints, and industry specific standards; (3) prototyping their solution, testing and validating their results.

Regarding student-led project topic to be described, the team investigated the potential market, concluding that there are no systems on the open market that augment the user’s perception to increase safety. The capstone design project course is designed over 3 quarters, with 3 credit course each quarter. The first quarter is dedicated to developing the project proposal, defining the concept, and framing the optimal solution of their project. The subsequent terms are dedicated to building the prototype, testing, and validating the results. The student design team has gone through multiple design iterations with the final version having just two main components. The compact design students came up made the system lighter and ultimately easier to use. The target material cost for each unit is $131 with a selling price for $350.

The significance of the methodology to be applied in this capstone course project is to combine theory and practice to prepare the students to become better problem solvers and obtain practical solutions to real life/simulated problems using a project-based approach. Senior Design capstone project has the following major goals. 1) Raise student awareness of contemporary issues as they relate to the Engineering Technology field. 2) Enhance student decision-making and problem-solving skills in a multi-attribute and team setting. Students in the Mechanical, Electrical, and Industrial engineering technology fields along with many others can learn many new skills from multi-disciplinary projects such as the design and development of the Personal Blind Spot Information System. There were many obstacles the student design team needed to overcome to produce the working prototype such as hardware breaking, components not seating correctly in the housings and too little power to guarantee 8 hours of use. Such projects and challenges show students how to use different types of technology and demonstrate how advanced technology can be used in an innovative product development. Overall, many different fields of engineering can benefit from this project application, enabling the development of skill and knowledge in many different engineering aspects and developing open-ended problem-solving skills. This capstone design project stimulates the students' interest in real-world product realization and prototyping.

Expected student learning outcomes assessment in this capstone course was performed using written reports and oral presentations as well as an evaluation of each student's contribution to the project. Oral presentations and written technical reports are assessed at the end of each three-quarter terms. Both written reports and oral presentations were assessed by all faculty members and several outside assessors from regional industries. The assessment of individual student contributions was performed by the project advisor and co-advisor. The students' performance was assessed using a set of performance indicators that are also used to assess the program's student 1-5 outcomes (ABET). Each indicator is assessed according to a Likert-type scale and the results weighted to emphasize technical qualities of the work and scaled to produce a score from 0 to 100 to determine the students' final grades.

The student-led capstone project description

The following describes the processes and techniques used in the development of the Personal Blind Spot Information System (P.B.S.I.S including a market analysis based on feedback from individuals currently working in industry. The student team found that there is a void in the market for a system like their concept. Operator safety is paramount, yet it is often overlooked.

The main purpose of the project is to develop a product that will enhance the personal safety industrial work area. When starting this project, as part of their market, literature and patent survey, students researched all patents related to operator safety to assure that they did not infringe on any previously conceived concepts. Students concluded that they were designing and pursuing a novel idea that has not previously been created. Students reach out to industry professionals, pitching their proposed solution through various events organized by the Drexel's Close School of Entrepreneurship and via their term presentations to industry-faculty panels. The feedback received led to major alterations to initial design: from a belt type design to a hat type of design. . Below there is an analysis of the initial design and all subsequent designs with the manufacturing processes planned to create them.

Problem Statement of the project

Students were expected to develop a problem statement of their challenge to solve, and below is the problem statement developed by our students for PSBIS.

Based on recent studies, , a company is expected to spend about $1.4 million, on average, if an employee dies on the job [1], on top of the lowered morale, inefficiencies created by an inexperienced replacement or the emotions experienced by the family all of which vary from case to case and are extremely difficult to prepare for. In 2016, 5,190 workers were killed on the job, of that 9.4% where struck by objects and 7.3% were caught in/between objects [2]. Injuries to employees have grave consequences at personal level, from the person being temporarily unavailable, to, in many industries, becoming a less valuable person on the employment market. This is especially a problem for a smaller company that does not have replacements at every level of the process. While preventing all injuries is ideal, it is also unrealistic. Reducing the risk of injury is the goal of the Personal Blind Spot Information System.

Initially, with the haptic design, the design team was very concerned that they may have issues with active patents. Listed below in Table 1 are all the patents related to the conceptual design. The students modified the design concepts to avoid infringing on any of their claims.

Table 1. Patents Related to Haptic Peripheral Personal Protection Equipment design

United States Patent #	Heading	Current Status
US9517175	*Tactile belt system for providing navigation guidance*	Active
US20160184731A1	*Haptic Control System*	Abandoned
US8378794	*System and method for transmitting haptic data in conjunction with media data*	Active
US20100152545A1	*Method and Apparatus For Providing A Haptic Monitoring System Using Multiple Sensors*	Active
US8461978	*Wireless ultrasound probe asset tracking*	Active
US20160124502A1	*Sensory feedback systems and methods for guiding users in virtual reality environments*	Public Domain

In addition to the patents listed above, two systems that played a role in either operator safety or perception augmentation were found. The HoloLens Mixed Reality headset is the product of a partnership between Trimble and Microsoft. This system is geared to for two-way communication with the environment. The headset knows what is in the surrounding area and can alter the image depending on the situation. Two major drawbacks of this system are that it does not notify the operator of a potential hazard and it costs nearly $4,000. Below is a picture taken from the Trimble website displaying the HoloLens unit.

Figure 1. Trimble Connect for HoloLens [7] (left), Amazon employee wearing Robot Deterring Vest [8] (right)

The second system found related to concept design was Amazon's Anti-Robot Safety Vest. This vest was developed by Amazon's own research and development team to alter a robot's course if a human is in the surrounding area. The vest tells the machinery, in this case robots, to slow down or stop when a human is present, but the design team's concept system tells the human that they need to pay attention to their surroundings that there may be a large moving vehicle behind them. Pictured above (Figure 1, right) is an Amazon employee wearing the vest in what is believed to be a robotic work zone. Since this vest is customized to perform in very specific environments, Amazon's warehouses, it is not currently for sale.

Product Design Specifications/Standards

The system was built using *ANSI/ISEA Z89.1-2014*as the Personal Blind Spot Information System is intended for industrial settings, therefore the hard hat it accompanies must be rated Type II. Type II is evaluated for impact attenuation and ingress protection from all major angles. Similarly, it must be Class E (electrical); resistant up to and including 20 kV [3].

The PSBIS is using an eye alerting system build using EN.166 Standard (European certification regulating eye protection). Sub-category: EN.166F requires both the frame and lens be able to endure the impact of a 6 mm ball weighing 86 grams contacting at a rate of 162 km/h. For approval, the lens must not detach [4].

Also, the system developed by the students was built in observance of the IP 65 standard that regulates resistance to penetration, otherwise known as the ingress protection - a scale established by the International Electro Technical Commission. If the system is to withstand a constant barrage of environmental abuse, it should be IP 65 classified. The first value (6) indicates total protection from dust ingress; the second value (5) indicates protection from low pressure water in any direction [5].

Design Iterations

When this project was started in August 2018, the design team planned on using a haptic belt system to alert the user of hazards via physical vibrations. These vibrations were going to have a directional aspect since the belt was covering all sides of the body. After testing, the sensors would be too weak to be felt through clothing and feedback from industry professionals confirmed that. As a team they decided it would be best to abandon the vibration sensors and move to a visual alert system [9].

The second version of the project consisted of a heads-up display module and a machine vision camera. The idea was to attach this new system to a hard hat and anything within a 60º cone behind the operator wearing the device. The camera can be programmed to detect a color, so for testing and demonstration purposes we used red with a moderate tolerance to the color hue. This design concept used 2 microcontrollers, one to control the camera and another to control the heads-up display. In addition to the 60◦ cone of the camera we implemented a radio frequency receiver to pick up any hazards with a tag. Functionally the design worked, but there were many improvements needed to be made.

The third version was based entirely on the idea of the previous, but with major improvements. The need for a second microcontroller was eliminated and the overall weight of the system was reduced. This improved battery life and compacted the design of the HUD. One major issue encountered was the RF receiver. In an industrial environment there is likely going to be RF feedback causing issues with the tags and the receiver. This could either set the system off or drown out an actual signal which defeats the purpose.

The final version solved the RF problem by removing it completely from the design. This reduced the modules needed to house components and allowed to package the entire system into just 2 different housings. Back housing secured the Pixy camera, the battery, an Arduino Nano and the ambient light sensor while HUD housing restrained the OLED and mirrors to reflect the message to the users eyeline. The latest design had an adjustable HUD module that could move 1.5" vertically and 75◦ horizontally across the face of the wearer. The team was able to reduce the weight of the housings to less than 1 lb. Even with the components the overall weight became less than similar products seen on the market [9].

Electrical Design

1. **Arduino Nano**: This is a lightweight microcontroller operating at 5 V and 19 mA. There are 22 digital pins and 8 analog pins for continuous signaling. The clock speed runs at 16 MHz, which allowed rapid I/O to and from external devices.
2. **Pixy2**: This machine vision camera tackles all image processing using its own built-in (dedicated) graphics card. The hard work is completed within the device then a simplified PASS/FAIL signal is output to the Arduino Nano for further instruction.
3. **Display** (OLED): A 0.66-inch diagonal screen with 64x48 pixels is used to output visual stimuli to the operator. The screen operated nominally in temperatures ranging from -30°C to 70°C, while requiring 3-5 V.
4. **Ambient Light Sensor**: The ambient light sensor checks the average lighting conditions to confirm validity of the visual processing output.
5. **Battery** (2000 mAh): It has a built-in guard to prevent over voltages, over currents, and under voltages. Without a load, the self-discharge rate is negligible; from than 8% per 30 days. The battery operates nominally at temperatures ranging -25°C to 60°C, thus deemed excellent for industrial settings
6. **MicroUSB Charger**: The battery requires a specialized lithium polymer charger. To maximize battery life, the chosen circuit progresses through three stages while charging.
   a. Preconditioning Charge
   b. Constant-Current Fast Charge
   c. Constant-Voltage Trickle Charge (to keep the storage held at maximum)

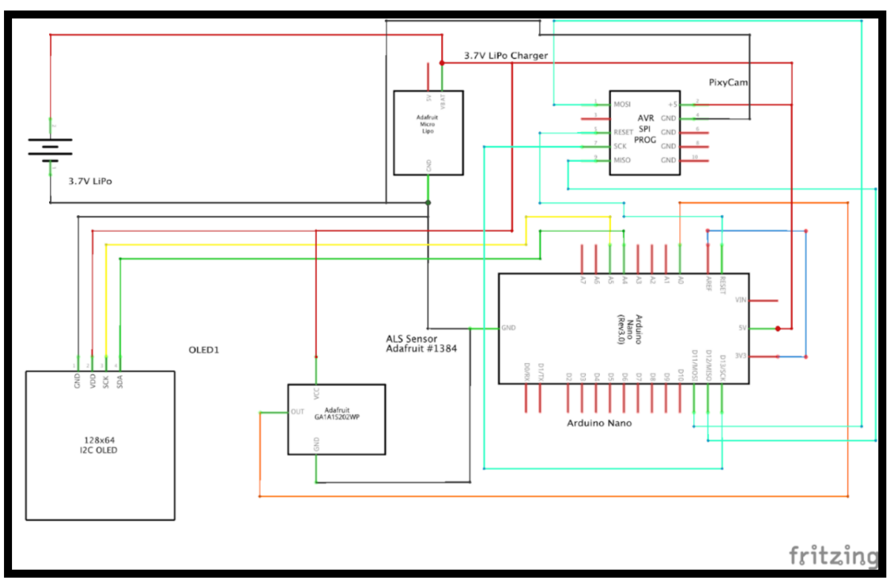

Figure 3. Circuit Layout [9]

Component Design

When designing the mechanical aspect to the P.B.S.I.S system, the design team had three key goals. Reduced weight, improved ergonomics and overall manufacturability of the system. All three goals needed to be optimal for the system to perform at peak functionality. With the more compact design, students only needed to create two main modules, the rear housing to hold most of the electronics and the HUD to hold the OLED and mirrors. Both modules would be secured to the hard hat via Velcro straps to allow the user the ability to adjust the size if their hard hats differ from the one tested with. To make the HUD module injection molding ready, 6 pieces were made to fit together. These were modeled by the students in SolidWorks CAD system and can all be seen in Figure 4 (as it was presented in the students' final report [9]).

The purpose of the HUD is to display a message to the user from an OLED. The message reflects off mirrors that line up with the wearers eyeline. Since everyone has different preferences the HUD has the ability to move either vertically (up to 1.5" of travel) and horizontally (75º side to side) giving the wearer full control of where the message is displayed. The user can also adjust how far screen is from their face, there is up to 2" of travel built into the module. These features should allow any user to find a comfortable position for the HUD.

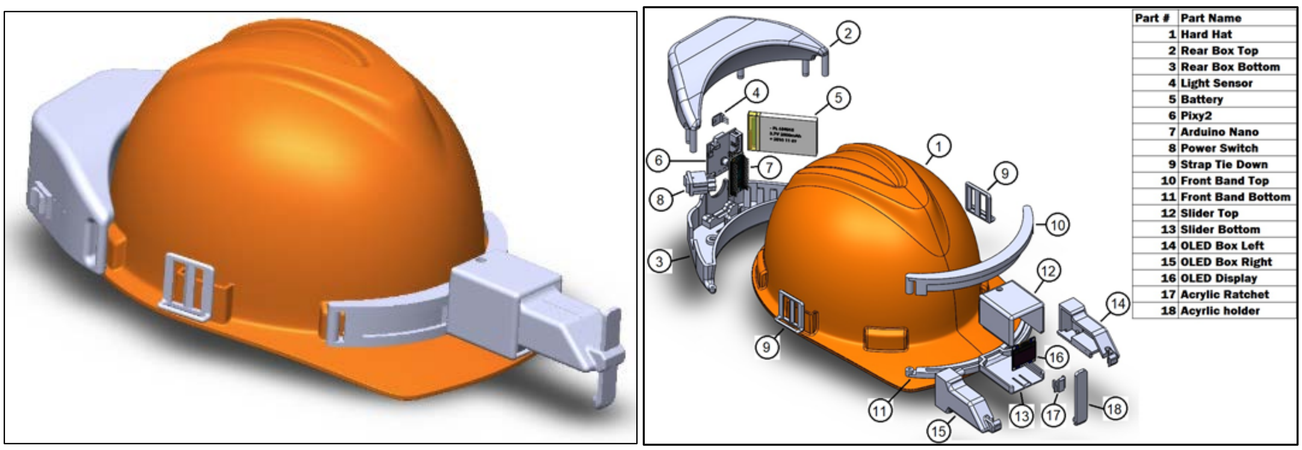

Figure 4. Full Assembly (left), Exploded View (right) [9]

The second module is designed to house the camera, microcontroller, battery, and the light sensor. The entire housing is comprised of only two pieces, a top and bottom. The top piece is secured to the bottom piece via screws. At no time should the screws come loose and potentially expose the internal parts to the environment.

ANSI/ISEA Z89.1-2014 states that a hard hat must withstand an impact of 850 lbf [1]. Figure 5 shows a SolidWorks structural simulation, performed by the student team, depicting the effect of the impact force applied to the rear housing: it produces a peak Von Mises stress of 71,270 psi and a peak strain of 0.20 in/in with 0.39 in maximum deformation. When those values are compared to the material of choice, ABS, it indicates material failure. While the design components do not need to be as robust as a hard hat, it is still preferred to have a system that can withstand the same abuse that a hard hat receives. To be capable of withstanding these impact force magnitude, three things can be done. The components walls can be made thicker, supporting structure can be implemented or a material with higher yield strength values can be used.

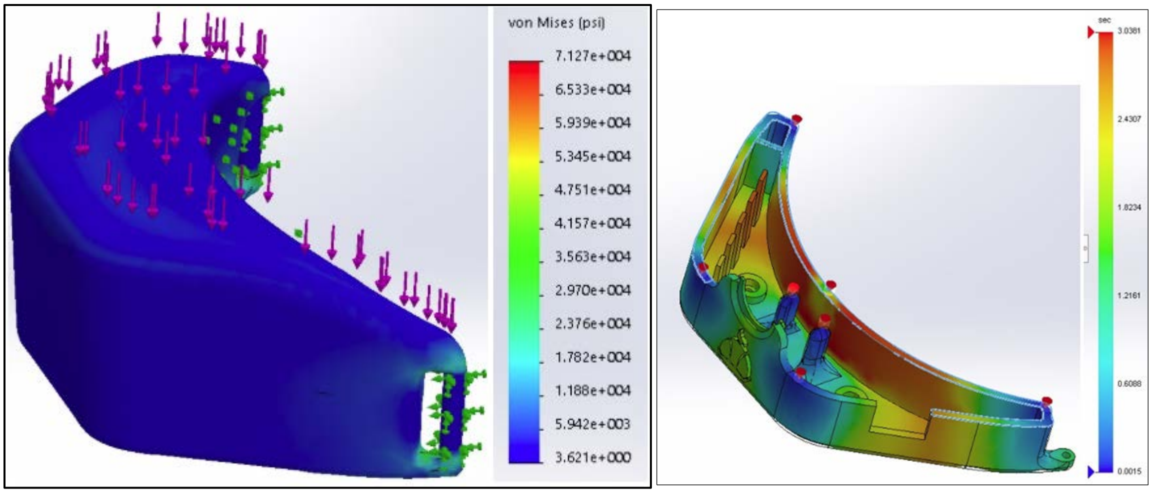

Figure 5. Rear Assembly- Von Mises (VM) Stress Simulation (Left). SolidWorks Plastics simulation of the molding process [9]

The students concluded that the ideal manufacturing of these pieces is injection molding, as being the cheapest and fastest way of producing plastic objects of this size on a mass scale. Since injection molding process is planned for the mass production, the students needed to use SolidWorks Plastics to simulate a molding process. For the simulation ABS with a melt temperature of 446 ◦F, a mold temperature of 122 ◦F with an injection pressure of 14503.8 psi was used. By far the most complex part was the rear bottom housing shown in Figure 5 (right) which needed 7 injection points. As a result, the piece takes 3.04s to fill and only reaches 3212.26 psi. Injection molding machines have an average range of 2-8 ton per square inch (4000 psi-16,000 psi). This means the process can be done below the standard range of most injection molding equipment. All component injection molding capability analysis was done successfully using SolidWorks plastics simulation [9].

The next step in their project development was to develop a Life Cycle Analysis, presented below.

Life Cycle Analysis

While most of the system was designed to last indefinitely with proper use and care, the following components will inevitably wear and degrade over time:

- Rechargeable battery
- Wires

The battery selected should last 400 charge cycles according to Battery University [6]. With 400 charges available and roughly 22 workdays per month, this gives 18 months of use per battery before they should be replaced. This does come at a cost to the customer at $11.25 per battery not including any labor costs to make that change. Each time a wire is bent, there is risk of permanently damaging it. Eventually the bending and twisting of a wire will cause it to break. The cost of this fix would be labor only since the wires come at virtually no cost when bought in bulk.

The other components such as the Arduino Nano, the Pixy Camera, the HUD and the housings do not have a limited life cycle unless exposed to elements outside the scope of testing. The camera, Arduino, OLED and HUD will function indefinitely if not exposed to temperatures outside the range of -25°C to 60°C as this is what they are rated for. Any temperature outside of that range can potentially damage the internal components that allow them to function properly. The housings will not naturally degrade, the main source of failure would be if they are dropped.

Market Analysis

The market analysis covers more than just the expected number of customers and units sold. Table 2 below shows the total expected costs and the expected profit from those costs.

The target customer is a small company with around 250 employees. With a small company of this size, paying large amounts of money due to an injury is potentially crippling. If someone must miss work due to an injury, they are less likely to have a replacement on hand compared to a large corporation with thousands of employees. It is estimated that 4-5 customers the first year can be found and then each year grow by about 5 customers. This requires 1000 units during the first year of production and then incrementally increase by 1000 units each year following. The table below shows the expected production rates.

Table 2. Expected Output Growth for the First 5 Years

Year 1	Year 2	Year 3	Year 4	Year 5
1000 Units	2000 Units	3000 Units	4000 Units	5000 Units

Manufacturing

The manufacturing of the concept system will be done in 2 stages. If the production rates stay near to the prediction, the low quantity will not offset the cost of starting and employing the injection molding process. Initially more cost-effective way for manufacturing will be with an additive manufacturing method of 3D printing for the first few years. After that, the design team planned to find an injection molder to make housings which will cut down on cost and lead times. The system has been modeled and designed to be injection molded, but after testing, it is believed that 3D printing the housings will not cause them to be structurally weaker.

The table below shows a forecast of the first method of production for the first 5 years using 3D printing. 5%-10% of profits each year will be reinvested to obtain more printers and updating old ones. This will ensure to have a quality product that is durable enough for all environments. The labor costs considered covering 5 people working for $12 an hour for a full 40-hour work week. 50 weeks of the year or 2000 working hours per person is estimated.

Table 3. Expected 5 Year Financial Plan Using 3D Printer Production Process

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Costs	$230,500.00	$228,559.30	$337,118.60	$445,677.90	$554,237.20	$662,796.50
Revenue		$350,000.00	$700,000.00	$1,050,000.00	$1,400,000.00	$1,750,000.00
Profit/Loss	-$230,500	$121,440.70	$362,881.40	$604,322.10	$845,762.80	$1,087,203.50
Total Profit/Loss						$2,791,110.50

Future Considerations

Over the course of this project, there have been ideas and alternative designs thought of pursuing but quickly realized were out of the scope of the project or would take too much time to complete. Some of these ideas included incorporating LEDs to notify the user along with the HUD, changing the camera to a different model which could detect multiple hazard codes simultaneously and redesigning the HUD to automatically retract when the helmet was taken off or the system was powered down. While incorporating any of these features would greatly improve the functionality and desirability of the system, they were not feasible for the project timeline. If another team in the future were to use this project as a starting point, it is suggested that starting with these features when looking for possible improvements.

Assessment and Student Outcomes

Oral presentations and written reports during the senior capstone course series were evaluated by Engineering Technology department faculty and qualified external engineering professionals according to the Likert-type scale. Also, faculty from School of Biomedical Engineering and Liaison Librarian for College of Engineering were invited to assess student projects. External assessors were from regional industry located in the Greater Philadelphia area and generally served as members of Industry Advisory Committee for the Engineering Technology program. Each assessor assigned a value for Performance Indicators according to a Likert-type scale for each ABET student outcome using ABET assessment sheet (Figure 7). Engineering Technology program is accredited by ABET-ETAC and already adopted 1-5 student outcomes for the general criteria. The assessment scale (rubric) indicated the following three levels: Exceeds, Meets, and Minimally Meets (these values may be interpolated resulting in a 5-level scale). These results were used to produce an average assessment of a student team's oral and written presentation. Overall assessment scores are provided in Figure 6 for fall, winter and spring quarters indicate that the senior design team attained ABET student learning outcomes in each assessed category. In addition to assessment by internal and external assessors, advisor of the project assigned scores for individual student performances (not shown in Figure 6).

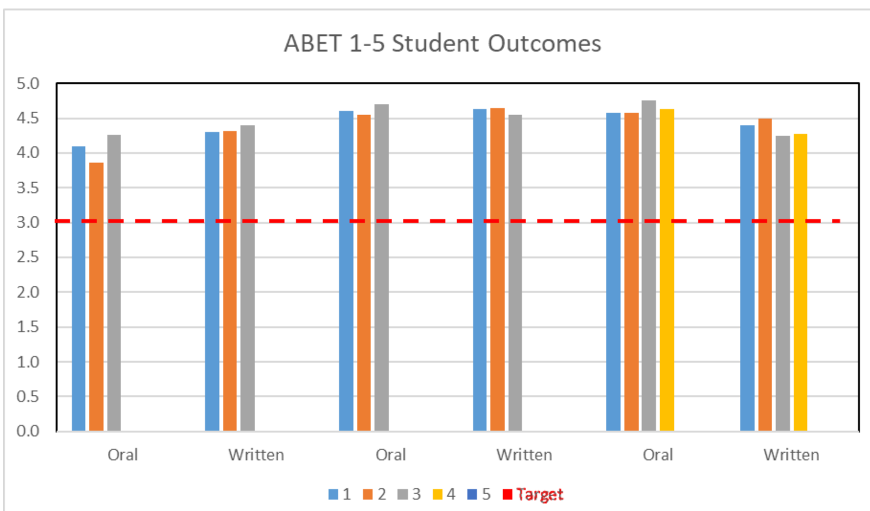

Figure 6. ABET assessment for Personal Blind Spot Information System senior design team during Fall, Winter and Spring 2018-19 AY.

Instructions: Write the score that best represents your evaluation of each Outcome/Performance Indicator. Interpolate score (e.g. 3.2) as needed. If performance indicator is not applicable, check N/A box.

	5	4	3	2	1	N/A
Outcome 1. /Performance Indicator 1. Demonstrates ability to apply knowledge of the discipline.	☐Can demonstrate comprehensive knowledge of the discipline with rare mistakes or errors.	☐	☐Can demonstrate knowledge of the discipline with few mistakes or errors.	☐	☐Often has difficulty demonstrating basic knowledge.	☐
	5	**4**	**3**	**2**	**1**	**N/A**
Outcome 1. /Performance Indicator 2. Demonstrates mastery of skills and modern tools used in their discipline.	☐ Can demonstrate comprehensive mastery of skills and modern tools of their discipline with rare mistakes or errors.	☐	☐ Can demonstrate mastery of skills and modern tools of their discipline with rare mistakes or errors with few mistakes or errors.	☐	☐ Often needs help when demonstrating skills used in the discipline.	☐
	5	**4**	**3**	**2**	**1**	**N/A**
Outcome 1. /Performance Indicator 3. Demonstrates an ability to apply knowledge of science and mathematics to engineering technology problems.	☐Can demonstrate comprehensive ability to apply knowledge of science and mathematics to engineering technology problems with rare mistakes or errors.	☐	☐Can demonstrate an ability to apply a knowledge of science and mathematics to engineering technology problems with few mistakes or errors.	☐	☐Often needs help to apply a knowledge of science and mathematics to engineering technology problems.	☐
	5	**4**	**3**	**2**	**1**	**N/A**
Outcome 1. /Performance Indicator 4. Demonstrates an ability to apply a knowledge of engineering and technology to engineering technology problems.	☐ Can demonstrate comprehensive ability to apply a knowledge of engineering and technology to engineering technology problems with rare mistakes or errors.	☐	☐ Can demonstrate an ability to apply a knowledge of engineering and technology to engineering technology problems with few mistakes or errors.	☐	☐ Often needs help to apply a knowledge of engineering and technology to engineering technology problems.	☐
	5	**4**	**3**	**2**	**1**	
Grading Normalized Scale	≥ 90%	≥ 80% <90%	≥ 70% <80%	≥ 60% <70%	< 60%	

Figure7. Sample (partial) ABET assessment sheet used for capstone senior design course for written report assessment during Spring 2018-19 AY.

In Engineering Technology program, we encourage our teams to participate at national and local competitions, they traditionally participate at industry sponsored events, presenting their projects to relevant industry experts. The *PBISIS* senior design project team participated at Drexel University's Week of Undergraduate Excellence and Lebow College of Business's Botstiber Competition. This competition is run by the Close School of Entrepreneurship in coordination with the College of Engineering during Fall quarter. The purpose of the competition is to educate students on certain principles of entrepreneurship as well as provide student teams with funding to enhance their design project development. In addition, the competition is used to identify design projects that may have commercial potential and then work with students to discuss incubation options should they choose to pursue commercialization efforts during their senior year and potentially after graduation. The project team was awarded $2000.00 towards building prototype and accomplishing project goals by the Botstiber Competition.

Conclusion

The *PBISIS-Personal Blind Spot Information System* project has been a success. The students have exceeded expectations and met the goals outlined in the scope of the project. At the end of the spring term they were able to say they succeeded. Even though they produced a working prototype there is still work that can be done. The current state of the prototype is not market ready. Improvements should be made before allowing consumers to use it. The machine vision camera worked, but the JeVois camera alternatively can do more allowing the system to be more versatile. Students did not have the power capacity or the time to implement this feature into the current design.

There were many obstacles the students needed to overcome to produce the working prototype such as hardware breaking, components not seating correctly in the housings and too little power to guarantee 8 hours of use. Through research, testing and multiple design iterations the design team was able to create a hard hat attachment that detected a hazard with at least 95% accuracy in an industrial environment. This system can potentially give operators nearly half a second more to react to a possible threat thus reducing the risk of injury or death while on the job.

Acknowledgements

Authors would like to recognize and thank the senior design team for their contribution to this project specifically Mr. Ryan Buckley, Mr. Benjamin Cohen, Mr. Douglas Forbes, & Mr. Michael Stine. Their hard work and valuable technical support paved the way for successful realization of the project. Also, Drexel University's Lebow College of Business's Botstiber Competition is acknowledged for their financial support during the project period.

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