

Spring 2016

The Smart Hard Hat

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Recommended Citation

Fyffe, Darcy; Langenderfer, Connor; and Johns, Charlton, "The Smart Hard Hat" (2016). *Honors Research Projects*. 267.

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BME Senior Design 4800:492

Honors Research Project Report

The Smart Hard Hat Team

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(Additional Team Members: Dominic Conte and Ben DeShon)

Honors Research Project Approvals

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Date

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Introduction

Among the most important factors for any company is employee safety. Take, for example, one of the world's largest and most international companies, General Electric (GE). GE has been around for over 130 years, and yet in the 2014 Annual report GE still discusses employee safety as one of its largest and most important goals [1]. With safety being a top priority for a top company it is easy to see that safety should be an important corporate pillar for any size business. Why? Because no matter the corporation, business segment, or location, a company cannot run without its most valuable asset: its employees. Millions of laborers around the globe go to work every day relying on basic safety devices, such as harnesses and steel-toed boots, to protect them. It is becoming essential that modern technological advances contribute to enhancing the safety of our workforce. It is with this thought that the Smart Hard Hat team set forth to improve the safety of workers everywhere by creating a personal protective equipment (PPE) device to monitor worker biometrics so as to prevent the effects of overexertion before potential injury can occur. Team Smart Hard Hat strived to do the following:

“Our mission is to design and develop a protective helmet that will satisfy the health and safety needs of our clients and consumer base, as well as our own personal standards of excellence. Our goal is to develop and construct a functioning protective headgear product that keeps the safety of the end user at the forefront of the design. In doing so, we will improve overall safety for indoor and outdoor workers by monitoring biometrics in order to reduce overexertion, survey cranial impacts, and ultimately decrease workplace injuries.”

Our proposed Smart Hard Hat device is intended for use by indoor and outdoor laborers to monitor biometrics as they perform their occupational duties. The device combines a variety of sensors and components, along with a central processing board to deliver immediate feedback alerts to both the worker and their supervisor if dangerous situations have occurred. By adding layers of technology, the Smart Hard Hat effectively increases protection for the worker from the hidden dangers of the job site, such as overexertion, heat exhaustion, concussive impacts and confined spaces. In a market dominated by brands such as 3M, Honeywell and MSA, the Smart Hard Hat provides a fresh approach to the Environmental Health & Safety (EHS) monitoring available to the most basic laborers. Keeping costs reasonable will ensure that this device is available to all levels of physical laborers. This project was not only meant to explore the hidden dangers inherent in any physically demanding field of labor, but to create a concept device that combats these dangers, which will lead to a more productive, and safer workforce.

Background Information

Approximately 6.5 million construction workers are at risk everyday of falling victim to hidden dangers innate to their jobs. A need exists to be able to monitor the worker's biometric signals so as to prevent the effects of overexertion before potential injury can occur. According to a 2012 white paper by the Occupational Safety and Health Administration (OSHA), over 4,500 workers lose their lives, and more than 4 million are seriously injured each year [2]. The Liberty Mutual Safety Index (2016) reported that the leading cause of injury among private sector workers in 2013 was overexertion, accounting for approximately 24% of all workplace injuries [3] (Figure 1).

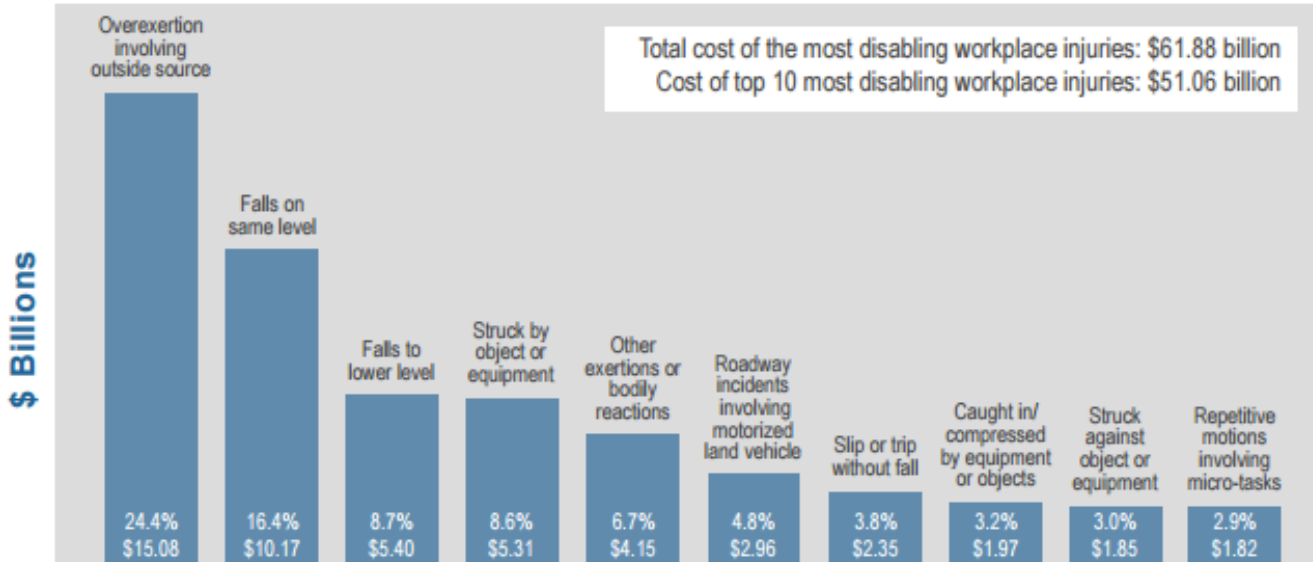


Figure 1. Top 10 Causes of Disabling Injuries in 2010. Adapted from Liberty Mutual Research Institute, 2016 [3]

Should the Smart Hard Hat device be expanded upon and brought to market, it would provide a myriad of benefits to many parties involved in the industry. Workers would experience a safer work environment, and avoid high amounts of physical, emotional, and financial hardship associated with injury, while employers will avoid many direct and indirect costs associated with worker injuries. According to the Liberty Mutual Workplace Safety Index (2016), the most disabling workplace injuries and illnesses in 2013 amounted to \$61.88 billion in direct costs, 24% of which is a direct result of overexertion [3], costing approximately \$15.08 billion. Increased worker production and safety will contribute to a decrease in indirect costs to the employers including: [2]

- Wages paid to injured workers during absence
- Time lost through reduced or light duty staff
- Administrative time spent by supervisors following injuries
- Employee training and replacement costs
- Lost productivity related to new employee training and accommodation of injured employees

Additionally, insurance companies will experience decreases in the magnitude of compensation benefits. The National Academy of Social Insurance reports that in 2012, workers' compensation covered around 128 million workers, providing approximately \$62 billion in benefits, a 1.3 percent increase from 2011 [4].

Based on market research conducted by Grandview Research, the global PPE market was valued at \$34 billion in 2014, and is expected to grow at a 7.2% compound annual growth rate to \$62.45 billion by 2022 (Figure 2) [5]. This growth is expected to result from increased demand for construction and industrial production. As this downstream activity increases, employers will purchase PPE in higher demands to comply with workplace safety regulations. Additionally, the high economic impact on companies from workplace injuries will further incentivize companies to

purchase innovative PPE products that go above and beyond to increase safety. Market research firm Radiant Insights reported that North America emerged as the leading regional market and accounted for 41.2% of total revenue in the industry in 2014. Moreover, the construction industry is anticipated to grow the fastest over the forecast period [6]. A PPE Manufacturing Report generated by IBIS World in 2015 indicates that within the United States, head protection make up approximately 24% of the ind

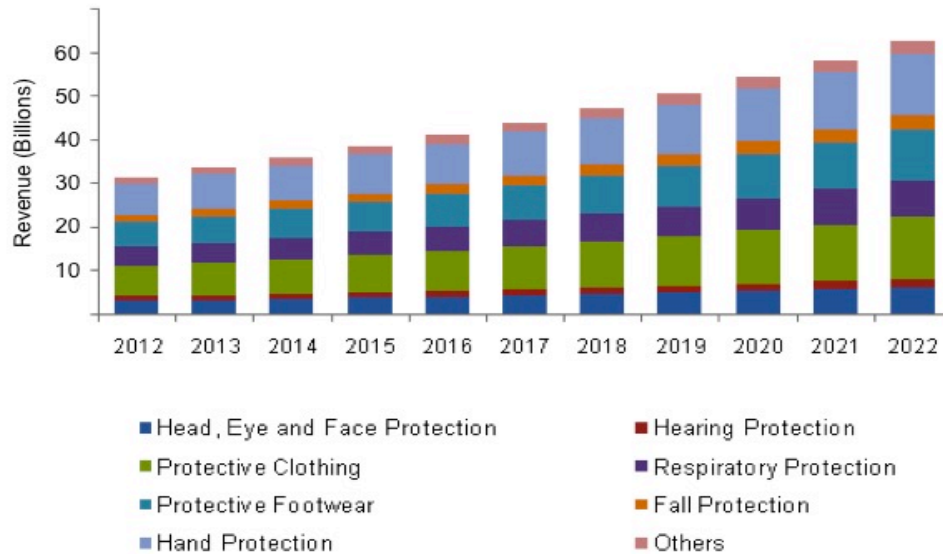


Figure 2. Projected Growth of Global PPE Market. Adapted from Grandview Research [5]

Competition in this market sector includes the major PPE Manufacturing Companies, 3M Company, MSA Safety Inc., and Honeywell International Inc., which combined hold 57.3% of the market [7]. We also face competition from smaller startup companies that produce innovative biometric monitoring protective equipment. Some existing products already on the market include the LifeBeam's Smart Bicycle Helmet and Smart Athletic Hat, which measure heart rate via an optical sensor, cadence, and calorie consumption during exercise. The measurement signals are sent wirelessly to the user's smartphone or fitness watch via Bluetooth [8]. Riddell's InSite Impact Response Football Helmet is fitted with a series of sensors and electrical components to evaluate the impacts sustained while on the field. In addition to monitoring the force, location, and intensity of the impacts, the helmet transmits alerts wirelessly to a monitor if impact thresholds are exceeded [9]. Schutt's Smart Football Helmet uses a thermistor to monitor the player's body temperature and an onboard radio transmits temperature readings in real time to a personal digital assistant (PDA) held on the sidelines [10]. Additionally, a new prototype hard hat product is being developed by Laing O'Rourke that combines a sensor array into an insert for retrofitting into an existing hard hat. This prototype monitors the temperature and heart rate of the worker, GPS location, and external temperature and humidity of the work environment. It utilizes a vibratory and auditory alert system for the wearer, and email or text message alerts can be sent to other parties [11]. There are also a variety of patents with similar technology and designs as our product, which we must not infringe upon should we bring the Smart Hard Hat to market. These patents are listed in the Engineering Requirements (Appendix A.2). Several of the designs utilize wireless transceivers that display alarms in response to events monitored by protective headgear via the use of biometric sensors. Although

the majority of patents have been listed in broad terms, patent #9,082,284 specifically identifies that the device be used to manage hazards on construction sites.

Our product differentiates from the competition by combining the key biometric sensors that can indicate danger to a worker (body temperature, heart rate, and concussive force) into one product, and transmitting that information through cellular data to a site supervisor using a Global System for Mobile Communication (GSM) board. This method of signal transmission is preferred over Bluetooth due to the long range of signal transmission capable while using GSM. Site supervisors will not need to carry around additional electronic alert equipment, and they will not need to be within wireless Bluetooth range to receive notification that their workers health and safety is in danger. The text message alerts include the worker ID, time, and the biometric threshold that has been exceeded. Additionally, there is an immediate feedback alert to the worker via a LED light on the hat brim, which indicates if a threshold has been exceeded. We concluded that a visual alert display was the optimal method of information transfer to the worker as opposed to auditory or vibratory. This is due to the often loud working conditions of a construction site, as well as manual labor activities (such as using a jackhammer) that would cause the vibratory alert to go unnoticed.

We determined which vital signs were the most important to measure, then researched the OSHA worker safety standards and the biometric limits that the human body can subject itself to before overexertion occurs. We have identified the following biometric thresholds:

Table 1. Biometric Thresholds

Biometric Signal	Minimum	Maximum
Temperature	96°F (35.5°C)	100.4°F (38°C)
Heart Rate	50 bpm	160 bpm
Impact Force	-	90g

The maximum threshold for temperature was selected as 100.4°F. This was based on a recommendation by The American Conference of Governmental Industrial Hygienists as described in Section III, Chapter 4 of the OSHA Technical Manual [12]. It is also the medical standard of body temperature for a fever. Heat stroke typically occurs when the body temperature reaches approximately 104°F, but the idea is that this device will help to prevent overexertion before it occurs. We have identified a minimum threshold for core temperature to prevent possible hypothermia as well. Since the body tends to enter hypothermia upon falling below 95°F [13], we set our threshold at 96°F as an alert. We have selected the minimum and maximum heart rate thresholds to be 50 bpm and 160 bpm respectively. The average resting heart rate for adults is typically between 60-100 bpm [14]. Dropping below 50 bpm can be dangerous and a sign of heart attack or cardiac arrest [15] for individuals that are not trained athletes. The average age of a construction worker in industry is 40.4 years [16], and the average maximum heart rate at that age for a healthy and athletically fit person is approximately 180 bpm [17]. Assuming that construction workers are not in a constant state of athletic exertion, we can lower this threshold to 160 bpm. Heart rates this

high can be an indicator of overexertion or a heart attack. Selecting the thresholds of 50 bpm and 160 bpm will provide enough time to alert the worker and their supervisor of possible overexertion or heart arrhythmias in order to follow appropriate safety protocol and reduce the risk of life threatening injuries. An impact acceleration value will lie between the range of 90-100g in order to cause a concussion, with studies tracking the impact forces received in football players who received concussions from head trauma indicating the acceleration force leading to a concussion to be at or above the 90g threshold [18]. As a note, while our hard hat looks to alert the user as accurately as possible, endless variations in head physiology and impact type means that no two head injuries are likely to be the same. An impact to one part of the head can cause trauma, while a separate impact to another region may not. For this reason, our impact force threshold is only meant to be a supplement to make a site foreman aware of head trauma, and is not intended to diagnose any type of head injury. All head injuries sustained on the worksite should be treated by a medical professional, regardless of force intensity.

Project Objectives and Goals

We set a variety of project objectives and goals that we aimed to meet by the completion of this project. First, we worked to develop a hard hat capable of detecting body temperature, heart rate, and impact forces. Additionally, the device should be capable of alerting both the worker and supervisor if the biometric values fall above or below the set safety thresholds, or if a distress button had been activated. A major aspect of this goal revolved around the research, selection process, and purchasing of sensors and circuitry components. The sensors and their biometric monitoring ability were critical to the overall design of the Smart Hard Hat, and a thorough selection process was of the utmost importance. We verified that these goals had been met by first testing an alpha unit in the form of a breadboard circuit, which confirmed the individual functionality of each component as well as their ability to work in tandem through an Arduino Uno microcontroller board. Once the accuracy and communicative ability between the components had been verified, the next step was to incorporate them within the shell of a hard hat. Unfortunately, we were unable to reach this portion of our product development goal due to limited time and schedule setbacks incurred throughout the year. During this phase, the hard hat would be controlled by its own local power source, in the form of a 9-volt battery. Additionally, in the interest of space and wiring integrity, the breadboard would be replaced with a flexible proto-board to which wires were soldered.

Our second goal was to work together as a team to follow a design process to develop a working prototype system. We outlined a general flowchart by which our design would take hold (Figure 3), as we developed our initial idea into a tangible, functional unit. We spoke to representatives from two construction firms - Summit Construction Co. of Akron, OH, and Eichley Engineers Inc. of Concord, CA - to discuss our concept and gather information regarding customer preferences in the construction industry. We used this information to develop a set of Customer Requirements (Appendix A.1) and corresponding Engineering Requirements (Appendix A.2) to serve as our design independent product targets. Our objectives were driven by these requirements as well as the limitations (Appendix A.3) of available resources and various other constraints. We were allocated a budget of \$500 for our project, which limited the quality of our components and

compelled us to think about and evaluate our purchase decisions carefully (Appendix E.1). In addition, we only had a single academic year to form and develop an idea into a functional unit.

We made significant progress toward our objectives throughout the academic year, as measured by our week-to-week goals and agendas we set for ourselves, and guided by our Gantt chart (Appendix D.1) and weekly group meetings. While we successfully completed our second goal of following the design process to develop an idea and transform it into a functional prototype, we did not make as much progress as we originally intended towards creating and testing a functional beta unit prototype.

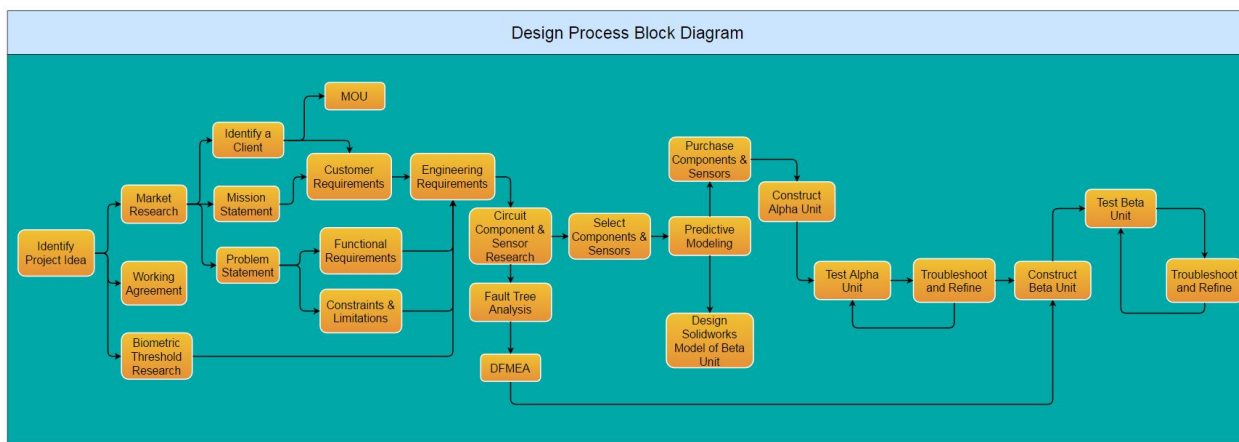


Figure 3. Design Process Block Diagram

Methods/Procedures/Manufacturing

After extensive research and predictive modeling, we developed a design for our product and purchased the necessary components (Appendix A.4) based on our decision analysis matrices. These components were used to build a basic prototype model of our Smart Hard Hat, which measures a predetermined set of biometrics and alerts the wearer/supervisor if those biometric limits have exceeded safety thresholds. Part of our research included weighing the attributes of potential component selections against one another in the form of Pugh matrices, so that we could arrive at component choices that best fit the scope of our project (Appendix A.5). Our predictive modeling included 1) a SolidWorks model (Appendix B.1) to identify placement of components as well as ensure that they would fit properly within the hard hat and 2) circuit analysis to identify the electrical consumption and requirements of each component and the alpha circuit as a whole. Using this analysis, we develop a circuit schematic (Appendix B.2) which outlined how and where our sensors and other electrical components would be connected. Although this research and modeling was very beneficial, and would eventually save us time and money in the long run, it did set us behind on our original schedule because we underestimated the amount of modeling that our project required.

Upon the arrival of the components, we individually connected each sensor to the Arduino Uno board and developed the necessary code to operate the sensors. This process involved a significant amount of troubleshooting, as well as gathering more information on how the Arduino code is written and utilized. In writing the code, our goals were to see successful operation of the sensors and other components in tandem, a visual display of accurate measurements, and proper

alerts if a biometric threshold was exceeded. At the onset of the comprehensive master code development, the thermistor, pulse sensor, accelerometer, and transmitter all had individual codes written as to allow the sensors to operate while attached to the Arduino board. After perfecting the individual codes, display readouts, and testing each of the components, we created a master code that used all of the sensors together simultaneously and provided an interface with the transmitter. We set thresholds in the master code to account for the biometric levels previously researched, so that if a limit is reached the transmitter is alerted. The transmitter would then send an alert to the supervisor via text message.

The advantage to first working with each component individually was that we had the opportunity to isolate problems and obstacles, as well as refine the code prior to compiling our master file. As we developed the overall code, we used the amount of memory available on the Arduino Uno board to store the sketches and operate the circuit as one of the coding constraints. After several versions of the code, we were able to lean the code so that it took up less than half of the onboard memory for the Arduino. In testing the code, we set the thresholds to lower levels than the biometric levels we researched so that we would not need to subject the initial circuit to extreme impacts or temperatures.

Performance Testing

As part of our alpha unit prototype, we developed a series of test protocols and conducted testing on each of the individual components to verify their functionality and ability to operate effectively and accurately within our device.

At the center of our design is our microcontroller, which ensures that all components are communicating properly and that all biometric signals are being evaluated. A testing protocol (Appendix C.1.1) was developed to test our Arduino Uno microcontroller. A sample code was uploaded to the board to test performance and each of the voltage pins were tested to ensure they were outputting accurate voltages. The final results for the microcontroller testing can be found in Appendix C.2.1.

Transmitting the signal is one of the most important differentiating factors for this project. The testing was based on the protocol, which can be found in Appendix C.1.2. The sample code that came with the breakout board was the initial code used for the testing. Using that code the FONA 800 GSM transmitter was tested by sending messages from Akron to 5 different locations, with distance varying from a few feet away all the way to California. The final results can be found in Appendix C.2.2. Since the transmitter is a go-no go feature, and all of the tests with the initial code, the transmitter passed its test protocol. Additionally, as each sensor was added into the final code, the transmission of the circuit was checked. Overall, throughout building the circuit the transmitter was tested 35 times. With each successful transmission the effectiveness of the transmitter was further proved.

The performance of the Adafruit 10K Precision Epoxy Thermistor - 3950 NTC was tested in order to verify its accuracy in sensing temperature, as well as to compare its actual resistance to its theoretical resistance (Appendix C.1.3). First, the theoretical resistance values provided with the thermistor were compared to readings by both the Arduino code and those obtained through use of a multimeter (Commercial Electric Model: MS8332C). The results (Appendix C.2.3) showed that there

were no significant differences between the measured and theoretical resistance values. Next, the accuracy of the thermistor's ability to measure temperature was assessed. The subject's temperature was measured at the axilla, with the arm fully adducted to hold the thermistor in place, and at the temporal artery, using a finger to hold the sensor in place. Once the readings stabilized, the temperature was recorded and then compared to a reading taken in the same locations by a digital thermometer. These measurements were taken 15 times at the axilla, and 10 times at the temple. The results (Appendix C.2.3) demonstrated a statistically significant difference in the measurement of temperature between the thermistor and the digital thermometer. In order to compensate for this difference, we can adjust the threshold to reflect the discrepancy. Since completion of our alpha unit, we have verified the thermistor's ability to communicate with the transmitter, but we still need to verify the signal has been sent as a result of our threshold values being exceeded. Once the thermistor has been incorporated into the hard hat assembly, it will also be important to verify the thermistor's ability to accurately read body temperature while the subject is in motion. This will be measured by tracking the subject's temperature while walking and at a light jog.

The Pulse Sensor Amped was tested in conjunction with a standard chest heart rate monitor (Polar FT1 Heart Rate Monitor) to determine the sensors accuracy at varying levels of physical intensity (Appendix C.1.4). The subject wore both monitors simultaneously and performed physical exercise at varying levels of intensity. The pulse sensor was worn around the subject's left thumb and was covered with athletic tape to reduce the level of ambient light interference. Ten measurements were taken at each level of physical intensity to ensure that statistically significant results could be obtained. The test results (Appendix C.2.4) were statistically evaluated using a two-sample t-test for each of the physical activity levels. Statistical analysis indicates that the means from the pulse sensor and the chest monitor are statistically equal for each of the activity levels (All P-Values > 0.05). We can conclude from our testing that, on average, the Pulse Sensor Amped (PPG sensor) records statistically equal values to that of a standard ECG chest heart rate monitor. However, we did notice a high level of variance during the pulse sensor readings. The rapid fluctuation of heart rate on the pulse sensor could be a result from motion artifacts or interference from ambient light. This observation was taken into account and the alpha unit code was adjusted to include a requirement for a sustained elevated heart rate for 30 seconds above threshold prior to an alert being sent.

The Sparkfun Triple Axis accelerometer (ADXL377) was tested using the motion-sensing rail equipment in place in the University of Akron's Physics lab department. In order to test the accuracy of the accelerometer against an established system, we performed several tests (Appendix C.1.5) using an on-rails system, which can measure a variety of metrics related to motion (position, velocity, acceleration, etc.). We secured our Arduino board, along with the attached accelerometer, to a cart that moves uniaxially along the track set up for the motion sensor array. We then performed a series of ten tests in which we rolled the cart, stopped it using our hand, and measured the acceleration values of both the motion sensor and the accelerometer. Our findings showed some statistical variance between the acceleration values recorded by the accelerometer and those shown in the motion-sensing system. Possible reasons for these differences include motion artifacts by a hand interfering with the sensor array, loose connections within the circuitry (as nothing up to this point has been soldered in place and may come loose with high impact), and variations related to the low acceleration values recorded. This is a recurring issue when testing the accelerometer; when looking

at concussion reports, most are recorded at much higher values than those tested in the lab. While our tests took the accelerometer up to 2-3g, a concussion scenario may cause upwards of 90g to the head. While our accelerometer is rated up to twice that, it becomes much harder to find a method of accurately measuring acceleration and comparing it to the values given at forces that high. In a production scenario, our approach to ensuring the functionality and accuracy of the accelerometers put into our hard hats would most likely involve approving a supplier who can be validated as consistently providing quality components, negating the need to perform incoming inspections on these parts in-house. Additionally, we could pursue the option of contracting testing with an outside company to validate the accuracy and functionality of the accelerometer with respect to applied forces.

Lastly, the distress button will also need to be tested to verify that it communicates with the transmitter consistently and sends an alert in the event the user would require immediate assistance. We have thus far verified its ability to send a signal to the transmitter; we just need to document its repeatability.

Future Directions

Due to the limited amount of time available to complete this project, we were unable to reach the level of product functionality we originally planned. In the future, the pulse sensor would need additional coding to isolate sources of signal interference in order to reduce fluctuation in the readings. This would allow for a more accurate and precise device to carefully measure the worker's heart rate. Additionally, several issues with the accelerometer readings indicate that some refinements would need to be made to accurately and consistently report concussive forces delivered to the hard hat. Like the pulse sensor, sources of error would need to be isolated in order to evaluate the underlying issues.

Presently, our development has moved past our Alpha unit towards the construction of the Beta unit. Unlike the tabletop build of the Alpha unit, the Beta unit requires each circuit element to fit within the enclosed space of a hard hat. Using our Solidworks model as a guide for sensor placement, we have designed a system to hold the components in place within the hard hat shell. This system must be able to securely hold onto the delicate components should the user experience an impact, drop the hat, etc. For this Beta system, we purchased a flexible, semi-permanent prototype board, or "proto-board" that would allow us to secure all components by way of soldering while still having the ease and functionality of a breadboard design. This proto-board will take up less room than our current breadboard, allowing us to secure all components within the hard hat and maintain the clearance necessary for the suspension of the hard hat to perform as intended. Once the components are secured in place, we would move on to developing a testing procedure to evaluate the functionality of the beta unit in the field. This includes sensor function and communication, battery life of the unit, security of components, and other metrics to be identified.

Due to constraints and limitations in regards to cost and time, there are several aspects of our device that could be implemented were we to take it past the scope of this project. Below is a list of future considerations if we were to bring the product to market:

- Testing for a standard hard hat (OSHA and ASTM)
- Weatherproofing

- More durable/secure moldings
- GPS functionality
- Different models with different feature levels (basic, intermediate and advanced models)
- Unique thresholds customized for each worker
- Two way communication for safety alerts to workers
- Hard-hat-to-hard-hat communication
- Color coordinated LED alerts to match the biometric limit exceeded
- Data storage
- Industrial-quality components (shifting away from plug-and-play and towards customized components)
- Quality Function Deployment to gain an in-depth picture of customer complaints and needs while prioritizing them for future product development

Many of the above would also require a market analysis to determine demand for these functionalities. By expanding the scope our analysis to receive more feedback from other companies we could determine what functionalities best suit the needs of a company's employees. Furthermore, after exploring market data we could create our very own sensor package in order to best meet these needs and sell it to our suppliers.

Additionally, we would ideally want to further test our beta unit in the field to ensure that the components can communicate well with the user interface in a real world scenario. This would allow us to troubleshoot and refine our design once introduced to obstacles that we may not experience in our bench-top testing of the alpha unit. Some of these obstacles can include disruption of signal due to blockage, motion artifacts of the sensors, or dislodging of the components within the hard hat.

References

- [1] General Electric. *GE 2014 Annual Report*, 2015. Web.
- [2] "Injury and Illness Prevention Programs White Paper." *OSHA.gov*. Occupational Safety and Health Administration U.S. Department of Labor, 2012. Web. 11 Nov. 2015.
- [3] Liberty Mutual Research Institute. (2016). 2016 Liberty Mutual Workplace Safety Index.
- [4] Sengupta, Ishita, Marjorie L. Baldwin, and Virginia Reno. "Workers' Compensation: Benefits, Coverage, and Costs (2012)." *National Academy of Social Insurance* Issue 17 (August, 2014). Web. 4 Mar. 2016.
- [5] "Global Personal Protective Equipment (PPE) Market By Product, By End-Use Expected to Reach USD 62.45 Billion by 2022." *Grandview Research*. Oct. 2015. Web. 4 Mar. 2016.
- [6] "Global Personal Protective Equipment (PPE) Market 2022 - Industry Trends, Market Size, Segments, Growth Prospects Report By Radiant Insights, Inc." *M2presswire* (2015): *Points of View Reference Center*. Web. 4 Mar. 2016.
- [7] Carter, Brittany. "Personal Protective Equipment Manufacturing." *IBIS World: Where Knowledge Is Power*. 1 May 2015. Web. 1 Sept. 2015.
- [8] "Smart Hat - LifeBEAM." *LifeBEAM*. Web.
- [9] Griggs, Brandon. "Smart Football Helmet May Help Detect Concussions - CNN.com." *CNN*. Cable News Network, 9 June 2014. Web. 2015.
- [10] Zarda, Brett. "A Smart Football Helmet Monitors Players' Health." A Smart Football Helmet Monitors Players' Health. *Popular Science*, 9 June 2009. Web.
- [11] Chanthadavong, Aimee. "Laing O'Rourke Monitors Workers' Safety with a Smart Hard hat." *ZDNet*. 18 Nov. 2015. Web. 7 Mar. 2016.

- [12] "OSHA Technical Manual (OTM) Section III: Chapter 4." *Occupational Safety & Health Administration*. N.p., 28 Apr. 2015. Web.
- [13] "Cold Stress." *ELCOSH : Electronic Library of Construction Occupational Safety and Health*. Construction Safety Association of Ontario, 2000. Web. 15 Nov. 2015.
- [14] "Slow Heartbeat." *Heart Rhythm Society*. Web. 12 Nov. 2015.
- [15] Fass, Bryan. "Heart Rate During a Heart Attack." *LIVESTRONG*. 24 Mar. 2011. Web. 12 Nov. 2015.
- [16] Welch, Laura. "The Aging Worker in the U.S. Construction Industry -- Occupational Health & Safety." *Occupational Health and Safety*. 10 Mar. 2010. Web. 1 Nov. 2015.
- [17] "Target Heart Rates." *American Heart Association*. 2015. Web. 13 Nov. 2015.
- [18] Bailey, Laura. "Football Helmet Sensors Help Researchers Demystify Concussion in Young Athletes." *University of Michigan*, 18 Apr. 2012. Web. 15 Nov. 2015.

Appendices

Appendix A: Design Documents

- A.1 Customer Requirements
- A.2 Engineering Requirements
- A.3 Project Limitations
- A.4 List of Materials
- A.5 Pugh Matrices

Appendix B: Modeling Documents

- B.1 Solidworks Models
- B.2 Circuit Schematic

Appendix C: Testing Documentation

- C.1 Testing Protocols
 - C.1.1 Arduino UNO Microcontroller Testing Protocol
 - C.1.2 Transmitter Testing Protocol
 - C.1.3 Thermistor Testing Protocol
 - C.1.4 Pulse Sensor Testing Protocol
 - C.1.5 Accelerometer Testing Protocol
 - C.1.6 Push Button Testing Protocol
- C.2 Test Results
 - C.2.1 Arduino Uno Test Results
 - C.2.2 Transmitter Test Results
 - C.2.3 Thermistor Test Results
 - C.2.4 Pulse Sensor Test Results
 - C.2.5 Accelerometer Test Results

Appendix D: Scheduling Documentation

- D.1 Gantt Chart

Appendix E: Budget Documentation

- E.1 Budget

Appendix A.1: Customer Requirements

Customer Requirements

The Smart Hard Hat

Members: Ben DeShon, Dominic Conte, Darcy Fyffe, Charlton Johns, and Connor Langenderfer

REVISION HISTORY

Version Number	Implemented By	Revision Date	Reason
1.0	DF	10/22/15	Initial Draft
1.1	CL, CJ, DF	11/10/15	Additions
1.2	Team	11/15/15	Additions
1.3	DF, DC	2/17	Revised to reflect customer requirements and table format

Introduction	
<p>In a wide variety of manual labor industries, workers are often unaware that they are approaching dangerous vital thresholds until they have already overexerted themselves. A need exists to be able to monitor the worker's biometric signals so as to prevent the effects of overexertion before potential injury can occur. The intention is to design and develop a protective helmet that will satisfy the health and safety needs of our clients and consumer base, as well as our own personal standards of excellence. We aim to develop and construct a functioning protective headgear product that keeps the safety of the end user at the forefront of the design. Our goal is to improve overall safety monitoring for indoor and outdoor workers by monitoring biometrics in order to reduce overexertion, survey cranial impacts, and ultimately decrease workplace injuries. This report contains the Product Design Specifications for the Smart Hard Hat biometric tracking PPE headgear device.</p> <p>Industries in need of a biometric safety monitoring PPE device:</p> <ul style="list-style-type: none"> • Construction • Indoor Manufacturing • Oil and Gas • Mining • Lumber • Athletics • Military 	
Section 1: Customer Usage Requirements	
1.1	Size: The headband shall be adjustable
1.2	Weight: Weight of the device shall be kept to a minimum in order to reduce unwanted strain on the wearer.
1.3	Comfort: Device will be able to be worn for an extended period without discomfort
1.4	Usability: Device will not require additional training prior to use
1.5	Usability: Device shall work out of box
1.6	Fit: Hard hat shall fit all users
1.7	Ergonomics: Device shall not limit head/neck movement of the user in any way
1.8	Placement: Internal circuitry components shall not interfere with outfitting the hard hat with accessories
Section 2: Regulatory Requirements	
2.1	Testing: Device shall be tested to ensure that the worker remains safe during impact

2.2	Testing: Device shall be tested to ensure that the worker remains safe in regards to electrical components
2.3	OSHA: Must meet all required OSHA standards
Section 3: Technical Requirements	
3.1	Temperature Measurement: Device shall accurately measure body temperature of the worker
3.2	Pulse Measurement: Device shall accurately measure heart rate of the worker
3.3	Impact Measurement: Device shall accurately measure impact forces inflicted on the worker
3.4	Distress Alert: Device will be able to send an immediate alert to supervisor if help is needed
3.5	Exceeded Threshold Alert: Device will be able to send an immediate alert to the worker if biometric limits are exceeded
3.6	Exceeded Threshold Alert: Device will be able to send an immediate alert to the supervisor if biometric limits are exceeded
3.7	Signal Transmission: Device will be able to send signals over a range of distances, terrains, and obstacles (walls, basements, etc.).
3.8	Power source: Battery shall be rechargeable or replaceable
3.9	Power source: Must provide sufficient power supply to operate the entire device
Section 4: Performance Requirements	
4.1	Duration: Device must function for the entire work period
4.2	Power: Device will contain an on/off power switch.
4.3	Alert: Device will alert supervisor if worker is in danger
4.4	Alert: Device will alert worker if they are in danger
4.5	Environment: Device shall operate in a variety of climates and environments (See Section 8)
4.6	Measurements: Device shall continuously monitor bodily biometrics regardless of worker activity
Section 5: Sales Requirements	

5.1	Cost: Cost will not exceed \$300
5.2	Aesthetic: Device will look similar to a standard hard hat
5.3	Aesthetic: Device will be available in a variety of colors
Section 6: Manufacturing Requirements	
6.1	Manufacturability: Device will be able to be ordered in bulk
6.2	Materials: Existing materials will be used for manufacture
6.3	Materials: Chosen materials must withstand environmental conditions
6.4	Materials: Materials shall be lightweight
6.5	Materials: Materials shall be resistant to wear
6.6	Materials: Materials shall be non-irritating to human skin
6.7	Materials: Materials must demonstrate required mechanical properties to safely perform function and adhere to standards
Section 7: Packaging and Transportation Requirements	
7.1	Packaging: Product shall not be damaged in transport
7.2	Package Dimensions: Product and insulation shall fit within standard size shipping container
7.3	Instructions: Each package to include one set of instructions for use
7.4	Labeling: Keep package upright, label required
Section 8: Environmental Requirements	
8.1	Normal Use: Components shall operate under standard environmental conditions.
8.2	Resistance to Adverse Weather: Components shall withstand environmental conditions such as rain, snow, high humidity, high wind, and extreme cold/heat.
8.3	Corrosion Resistance: Components shall withstand humidity on the interior of the hat caused

	by perspiration and high temperature.
8.4	Packaging: Packaging shall be resistant to extremes in temperature, humidity, and adverse weather conditions
8.5	Cleaning: Components of the hard hat shall be cleaned without incurring damage.

Appendix A.2: Engineering Requirements

Engineering Requirements

The Smart Hard Hat

Members: Ben DeShon, Dominic Conte, Darcy Fyffe, Charlton Johns, and Connor Langenderfer

REVISION HISTORY

Version Number	Implemented By	Revision Date	Reason
1.0	DF	10/22/15	Initial Draft
1.1	CL, CJ, DF	11/10/15	Additions
1.2	Team	11/15/15	Additions
1.3	BD, DF	3/22/16	Updated content to reflect engineering requirements as related to customer specifications

1. INTRODUCTION

1.1. Purpose of the Smart Hard Hat Engineering Requirements Document

In a wide variety of manual labor industries, workers are often unaware that they are approaching dangerous vital thresholds until they have already overexerted themselves. A need exists to be able to monitor the worker's biometric signals so as to prevent the effects of overexertion before potential injury can occur. The intention is to design and develop a protective helmet that will satisfy the health and safety needs of our clients and consumer base, as well as our own personal standards of excellence. We aim to develop and construct a functioning protective headgear product that keeps the safety of the end user at the forefront of the design. Our goal is to improve overall safety monitoring for indoor and outdoor workers by monitoring biometrics in order to reduce overexertion, survey cranial impacts, and ultimately decrease workplace injuries. This report contains the Product Design Specifications for the Smart Hard Hat biometric tracking PPE headgear device.

Industries in need of a biometric safety monitoring PPE device:

- Construction
- Indoor Manufacturing
- Oil and Gas
- Mining
- Lumber
- Athletics
- Military

This document outlines the engineering requirements necessary for developing a product that meets the customer requirements.

2. Customer Usage Requirements

2.1. Size

- 2.1.1. The size range of commercial helmet sizes, from at least 6 ½ to 8 inclusive, shall be accommodated by one or more headbands [1].
- 2.1.2. The surface of the headband, in contact with the wearer's head, shall not be less than one-inch nominal width [1].

2.2. Weight

- 2.2.1. The total weight of the device shall not exceed 15 oz. for Class A or C helmets, and 30 oz. for Class D helmets [1].

2.3. Comfort

- 2.3.1. Suspension shall consist of a design that is soft, pliable, and conforms to the contours of the wearer's head.
- 2.3.2. Device shall utilize a sweatband that is soft, moisture absorbent, and able to quickly wick and evaporate moisture.

2.4. Usability

- 2.4.1. IFU (Instructions for Use) shall be included with each device.
- 2.4.2. Components shall be calibrated prior to shipment.
- 2.4.3. No assembly shall be required by the end user.

2.5. Fit

- 2.5.1. Hard hat shall be one size fits all with adjustable interior.

2.6. Ergonomics

- 2.6.1. The product shall be intuitive for the worker.
- 2.6.2. The product shall add no opportunity cost to a physical laborer.
- 2.6.3. The product shall add minimal information access costs for the supervisor.
- 2.6.4. The product shall be comfortable to wear for the user.
- 2.7. Placement**
 - 2.7.1. Internal components shall be placed within the shell of the hat, not in contact with suspension.
 - 2.7.2. Internal components shall not utilize accessory slots.

3. Regulatory Requirements

3.1. Testing

- 3.1.1. Hard hat shall protect worker in adherence to ANSI Z89.1 standards.
- 3.1.2. Device shall comply with IEC 61508 for electronic functional safety.

3.2. OSHA

- 3.2.1. Device must meet OSHA standard 1910.135 for head protection.
- 3.2.2. Device must meet OSHA standard 1926.100 for head protection.

3.3. Intellectual Property

Existing patents (USPTO) that shall not be breached are included, but not limited to:

- 9,129,499: Wireless Device for Monitoring Protective Headgear [2]
- 8,860,570: Portable wireless personal head impact reporting system [3]
- 9,082,284: Real time safety systems [4]
- 8,884,756: Monitoring device for use with protective headgear [5]
- 6,798,392: Smart Helmet [6]
- 20070177651: Body temperature measuring device for helmet or head gear [7]

4. Technical Requirements

4.1. Temperature Measurement

- 4.1.1. Must accurately and continuously measure body temperature ± 0.2 °F.
- 4.1.2. Must be able to detect body temperature range of 90 °F – 110 °F.
- 4.1.3. Must be compatible with the 9-12V range of the microcontroller.
- 4.1.4. Must be able to communicate with logic board continuously.

4.2. Pulse Measurement

- 4.2.1. Must accurately and continuously measure workers heart rate.
- 4.2.2. Must be able to detect pulse range of 0 - 300 bpm.
- 4.2.3. Must be able to communicate with logic board continuously.
- 4.2.4. Must be compatible with the 9-12V range of the microcontroller.
- 4.2.5. Must be able to obtain accurate pulse reading from the body placement of sensor.

4.3. Impact Measurement

- 4.3.1. Must be able to detect and alert impact forces above a 90g threshold.
- 4.3.2. Must be able to communicate with logic board continuously.
- 4.3.3. Must be compatible with the 9-12V voltage range of the microcontroller.
- 4.3.4. Must not be activated by normal worker movement, dropping of the hat, etc.

4.4. Distress Alert

- 4.4.1. Distress button must be a passive system unless put into the circuit by the user.
- 4.4.2. When activated, the distress button must communicate directly with the microcontroller.
- 4.4.3. Distress button must be “go/no-go” in order to ensure signal shall be sent.
- 4.4.4. Must be placed in such a manner to prevent accidental activation.
- 4.4.5. Must be compatible with the 9-12V range of the microcontroller.

4.5. Exceeded Threshold Alert

- 4.5.1. Biometric values above set thresholds shall trigger a visual LED display to alert the worker.
- 4.5.2. Biometric values above set thresholds shall trigger an alert message sent via SMS to the site supervisor.

4.6. Signal Transmission

- 4.6.1. Microcontroller
 - 4.6.1.1. Must be able to communicate with all components.
 - 4.6.1.2. Must be able to identify body temperature threshold of 100.4 °F.
 - 4.6.1.3. Must be able to identify heart rate threshold of 160 bpm [8][9].
 - 4.6.1.4. Must be able to identify an impact force threshold of 90g[10].
 - 4.6.1.5. Must communicate any data outside of threshold range with data transmitter.
 - 4.6.1.6. Must monitor and process data from sensors continuously.
 - 4.6.1.7. Must initiate feedback alert to user if thresholds are exceeded.
- 4.6.2. Data Transmission
 - 4.6.2.1. Data transmitter must have signal strength to cover an entire work site, industry recommendations dictate a minimum of 250 yards line of sight distance, however a farther range is preferable [11].
 - 4.6.2.2. Data transmitter must have a GSM compatible antenna to properly transmit data.

4.7. Power Source

- 4.7.1. Power source shall supply no less than 9V and no more than 12V to the device.
- 4.7.2. Power source must last for the duration of the 8 hour work period.
- 4.7.3. Power source must be rechargeable or replaceable.
- 4.7.4. Power Source shall not give off levels of heat that provide discomfort or hazard to the worker.

5. Performance Requirements

5.1. Duration

- 5.1.1. Device shall function accurately for the duration of the 8 hour work day.

5.2. Power

- 5.2.1. Device shall contain an on/off switch.

5.3. Supervisor Alert

- 5.3.1. Device shall send a text message via SMS to a pre-identified number to alert the supervisor of the exceeded biometric limit.
- 5.3.2. The message shall display the individual ID Number and a predetermined alert phrase if the distress option of the Smart Hard Hat is activated.
- 5.3.3. The messaging service shall be compatible with all SMS-enabled phones.
- 5.3.4. Data transmitter requires access to SMS network in order to transmit data.

5.4. Worker Alert

- 5.4.1. Device shall send an immediate visual feedback alert to the worker to indicate an exceeded biometric limit.

5.5. Environment

- 5.5.1. Device shall function in all standard environmental conditions and a variety of adverse weather conditions. See 'Environmental Requirements' below for details.

5.6. Measurements

- 5.6.1. Circuitry components will be secure within the device.
- 5.6.2. Biometric sensors will maintain constant contact with the wearer.

- 5.6.3. Circuitry code will take into account ambient light and movement artifacts, as well as observed variances between the sensor and standard measuring equipment.

6. Sales Requirements

6.1. Cost

- 6.1.1. Production costs shall not exceed \$100 per unit
- 6.1.2. Final retail price for the device shall not exceed \$250 per unit

6.2. Aesthetics

- 6.2.1. Device shall be manufactured so as to maintain the aesthetics of a regular hard hat. All electronic components shall be incorporated internally and not interfere with the normal operating function of the hard hat shell.

7. Manufacturing Requirements

7.1. Manufacturability

- 7.1.1. Device shall be manufactured through a facility that employs cGMP (Current Good Manufacturing Practices) and has a current Quality System in place.

7.2. Materials

- 7.2.1. Existing materials for manufacture shall be used.
- 7.2.2. Chosen materials must withstand necessary environmental conditions (see 'Environment').
- 7.2.3. Materials shall be lightweight within designated limitations (see 'Weight').
- 7.2.4. Materials shall be resistant to wear. (See 'Service Life').
- 7.2.5. Materials shall be non-irritating to human skin.
- 7.2.6. Materials must demonstrate required mechanical properties to safely perform functions (see 'Performance') and adhere to testing standards (see 'Standards').

7.3. Service Life

- 7.3.1. OSHA does not specify the service life of a hard hat, and there is no standard expiration time frame for hard hats. The life span of a hard hat may vary depending on the conditions at each work site. General manufacturing guidelines suggest that the suspension be replaced after no more than 12 months and the entire hat be replaced after no more than five years. If wear or damage is observed on either portion of the hat, it shall be replaced immediately ^[9].
- 7.3.2. Electronic components shall be checked every 3 months for wear and every 6 months for verification that sensors are still calibrated and working to transmit data properly. After any traumatic event is triggered the components shall be re-evaluated and checked for normal functionality.

8. Packaging and Transportation Requirements

8.1. Packaging

- 8.1.1. Device shall be packaged in such a way as to ensure the integrity of all internal components in case of accidental drops or impacts.

8.2. Instructions

- 8.2.1. IFU (Instructions for Use) shall be included in each packaged device.

8.3. Labels

- 8.3.1. Labels shall contain any relevant safety information, as well as all relevant manufacturing identification and Regulatory requirements (country of origin, lot/batch number, date of manufacture, etc.)
- 8.3.2. Labels will include a description of the product identity
- 8.3.3. Labels will include a declaration of the net quantity
- 8.3.4. Labels will include the company name and place of business

9. Environmental Requirements

9.1. Normal Use

- 9.1.1. The device shall perform and not be damaged within the temperature range of -20 °F – 150 °F (-28.9 °C - 65.5 °C).

9.2. Resistance to Adverse Weather

- 9.2.1. Components shall be able to withstand environmental conditions such as rain, snow, high humidity, high wind, and extreme cold/heat.

9.3. Corrosion Resistance

- 9.3.1. Components shall be able to withstand humidity on the interior of the hat caused by perspiration and high temperature.

9.4. Packaging

- 9.4.1. Device will be packaged in standard U.S. shipping containers.
- 9.4.2. Packaging will include materials that will aid in the preservation of product quality if faced with adverse weather, drops, or impacts.

9.5. Cleaning

- 9.5.1. The hard hat shell must be able to withstand cleaning with mild soap and water.
- 9.5.2. The hard hat is to be stored away from direct sunlight.
- 9.5.3. The end user shall not use paints, chemicals, adhesives, or any chemical solvent that may prematurely degrade the hard hat or its internal components.
- 9.5.4. Sensors shall be calibrated as recommended in the user manuals to ensure proper measurements and function.
- 9.5.5. The power source shall be inspected every 6 months to ensure the device functions as intended.

10. References

- [1] American National Standards Institute. ANSI Z89.1-2014: Safety Requirements for Industrial Head Protection. June 03, 2014.
- [2] Howard, John W., and Richard Cutler. Wireless Device for Monitoring Protective Headgear. THL Holding Company, LLC, Round Rock, TX (US), assignee. Patent US 9,129,499 B2. 8 Sept. 2015. Print.
- [3] Thomas, Bijju, and Timothy Bauer. Portable Wireless Personal Head Impact Reporting System. SenseTech, LLC, assignee. Patent US 8860570 B2. 14 Oct. 2014. Print.
- [4] Prieto, Robert. Real Time Safety Systems. Fluor Technologies Corporation, assignee. Patent US 9082284 B2. 14 July 2015. Print.
- [5] Howard, John W., and Richard Cutler. Monitoring Device for Use with Protective Headgear. THL Holding Company, LL, assignee. Patent US 8884756 B2. 11 Nov. 2014. Print.
- [6] Hartwell, Peter G., and James A. Brug. Smart Helmet. Hewlett-Packard Development Company, L.P., assignee. Patent US 6798392 B2. 28 Sept. 2004. Print.
- [7] Daugherty, Edward, and Craig Daugherty. Body Temperature Measuring Device for Helmet or Head Gear. Daugherty Edward P, Craig Daugherty, assignee. Patent US 20070177651 A1. 2 Aug. 2007. Print.

- [8] Welch, Laura. "The Aging Worker in the U.S. Construction Industry -- Occupational Health & Safety." *Occupational Health and Safety*. 10 Mar. 2010. Web. 1 Nov. 2015.
- [9] "Target Heart Rates." *American Heart Association*. 2015. Web. 13 Nov. 2015.
- [10] Bailey, Laura. "Football Helmet Sensors Help Researchers Demystify Concussion in Young Athletes." University of Michigan, 18 Apr. 2012. Web. 15 Nov. 2015.
- [11] Saunders, Barbara. "Biosensors to Prevent Heat Stroke Unveiled as Petro-Safety Tools." *NEWS Rigzone*. 9 Jan. 2012. Web.

Appendix A.3: Project Limitations

The following constraints and limitations will impact the Smart Hard Hat design:

- The weight of the hat - can not introduce unwanted strain on workers
- The cost cannot exceed \$500
- The time required to create a functioning prototype is limited to the academic year and must be completed by the end of April 2016
- Team has limited experience working with sensors and electrical circuits
- Hard hat must meet ANSI/ISEA Z89.1-2009 testing standards for hard hats (if brought to market)
- Sensors, Transmitters, Receivers, and other components must be compatible
- Hard hat must have a communicative range that is useful for any work zone size
- Hard hat must have a battery life that functions for the length of an entire work shift
- Resources are limited to the abilities of our team and the contributions of our client (Not just in terms of money, but also experience, testing machines, PPE knowledge/data, etc.)
- Quality of the finished prototype will be constrained by time and resources

Appendix A.4: List of Materials

The following are a current list of materials used in the Smart Hard Hat design:

- Arduino Uno Rev 3
- Breadboard
- Flexible Protoboard
- Jumper wires
- Resistors (10 k Ω , 220 Ω)
- Pulse Sensor Amped
- SparkFun ADXL377 Triple Axis Accelerometer Breakout
- 10k Precision Epoxy Thermistor
- 1 x 16mm Illuminated Pushbutton - White Momentary
- FONA 800 GSM Transmitter
- Slim Sticker-type GSM/Cellular Quad-band Antenna
- Lithium Ion Polymer Battery - 3.7v 500mA
- USB cable - A/MicroB (3ft)
- T-Mobile Sim Card
- 9V Battery
- Bright LED bulb
- Mutual 50215 Polyethylene 6-Point Ratchet Suspension Hard Hat, White

A.5: Pugh Decision Matrices

Logic Board Selection:

Criteria	Weight	Arduino Uno		Adafruit FLORA	
		Rating (-1,0,1)	Weighted Score	Rating (-1,0,1)	Weighted Score
Cost	2	0	0	0	0
Memory Capacity	3	1	3	0	0
Ease of use	3	1	3	1	3
Durability	2	0	0	-1	-3
Online Resources	2	3	1	0	0
Size	2	0	0	1	2
Total Score		7		2	
Rank		1		2	

Scoring Details for Logic Board Selection:

Criteria	Arduino Uno	Adafruit FLORA
Cost	~\$25, not a significant price point difference from FLORA	\$20 not a significant price point difference from Arduino
Memory Capacity	Due to increased size, Arduino has more space for code	Small size yields less space for a functional code
Ease of use	Plug-and-play for easy switching of sensor networks	Requires soldering for connections to board
Durability	Not they sturdiest, but no extra worry from misconnecting power supply	Potential to fry circuit if power supply connected incorrectly
Online Resources	Many available on Arduino website as well as various forums	Less resources available across the web
Size	Not as small as the FLORA but small enough to fit within our project	Main draw for this unit, easy to fit inside a hard hat

Transmitter Selection:

Criteria	Weight	433MHz SX1278 Long Range RF Wireless Transceiver Module		RFM92W 915Mhz 20dBm LoRa Transceiver		FONA 800	
		Rating (-1,0,1)	Weighted Score	Rating (-1,0,1)	Weighted Score	Rating (-1,0,1)	Weighted Score
Accuracy	1	1	1	1	1	1	1
Durability	2	0	0	-1	-2	1	2
Cost	1	1	1	1	1	-1	-1
Size	4	-1	-4	0	0	0	0
Communication to logic board	5	0	0	0	0	0	0
Ease of programming	2	-1	-2	-1	-2	1	2
Distance	5	0	0	0	0	1	5
Reusability	3	1	3	0	0	0	0
Reliability	3	1	3	0	0	0	0
Set-up for receiving end	5	-1	-5	-1	-5	1	5
Total Score		-3		-7		14	
Rank		2		3		1	

Scoring Details for Transmitter Selection:

Criteria	433MHz SX1278 Long Range RF Wireless Transceiver Module	RFM92W 915Mhz 20dBm LoRa Transceiver	FONA 800
Accuracy	-	-	-
Durability	-	-	-
Cost	\$8	\$9	\$40
Size	-	-	-
Communication to logic board	Arduino	Arduino	Arduino
Ease of programming	Not much support	Not much sample code	Lots of sample code
Distance	13 miles	12 miles	Global
Reusability	-	-	-
Reliability	-	-	-
Set-up for receiving end	Requires additional software	-	Text message

Thermistor Selection:

Criteria	Weight	10K Precision Epoxy Thermistor - 3950 NTC		SKIN PROBE W/400 SERIES TEMP		TSD202B Skin Temp Surface Probe Thermistor		LilyPad Temperature Sensor	
		Rating (-1,0,1)	Weighted Score	Rating (-1,0,1)	Weighted Score	Rating (-1,0,1)	Weighted Score	Rating (-1,0,1)	Weighted Score
Accuracy	2	1	2	1	2	1	2	-1	-2
Continuous	2	0	0	0	0	0	0	0	0
Durability	2	0	0	0	0	0	0	1	2
Cost	3	1	3	-1	-3	-1	-3	1	3
Size	2	1	2	1	2	1	2	0	0
Communication to logic board	3	1	3	0	0	0	0	1	3
Ease of programming	3	1	3	0	0	0	0	1	3
Sensor placement (location)	1	1	1	1	1	0	0	1	1
Reusability	2	1	2	-1	-2	1	2	1	2
Plug-and-play	3	1	3	0	0	0	0	1	3
Availability of supply	2	0	0	-1	-2	0	0	0	0
Total Score		19		2		6		10	
Rank		1		4		3		2	

Scoring Details for Thermistor Selection:

Criteria	10K Precision Epoxy Thermistor - 3950 NTC	SKIN PROBE W/400 SERIES TEMP	TSD202B Skin Temp Surface Probe Thermistor	LilyPad Temperature Sensor
Accuracy	-	-	-	Low accuracy according to reviews
Continuous	-	-	-	-
Durability	-	-	-	-
Cost (w/o shipping and tax)	\$4.00	Approx. 40	\$155.00	\$4.95
Size	-	-	-	-
Communication to microcontroller	Made for Arduino	-	-	Made for Arduino
Ease of programming	Fully functional code available	Can develop code	Can develop code	-
Sensor placement (location)	Anywhere	Forehead, axilla	Anywhere on skin	-
Reusability	Yes	No	Yes	Yes
Plug-and-play	Yes	No	No	Yes

Availability of supply	1	50	1	1
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Pulse Sensor Selection:

Criteria	Weight	Pulse Sensor Amped		SPO2 e-Health Sensor		ECG e-Health Sensor	
		Rating (-1,0,1)	Weighted Score	Rating (-1,0,1)	Weighted Score	Rating (-1,0,1)	Weighted Score
Accuracy	2	0	0	0	0	0	0
Continuous	2	0	0	0	0	0	0
Durability	2	0	0	0	0	-1	-2
Cost	3	1	3	-1	-3	-1	-3
Size	2	1	2	0	0	1	2
Communication to microcontroller	3	1	3	0	0	0	0
Ease of programming	3	1	3	0	0	0	0
Sensor placement (location)	1	1	1	-1	-1	0	0
Reusability	2	0	0	0	0	-1	-2
Plug-and-play	3	0	0	0	0	0	0
Availability of supply	2	0	0	0	0	0	0
Total Score		12		-4		-5	
Rank		1		2		3	

Scoring Details of Pulse Sensor Selection:

Criteria	Pulse Sensor Amped	SPO2 e-Health Sensor	ECG e-Health Sensor	AdInstruments Pulse Transducer
Accuracy	-	-	-	-
Continuous	-	-	-	-
Durability	-	-	-	-
Cost (w/o shipping and tax)	\$25	Approx. \$40	Approx. \$61	Unknown
Size	-	-	-	-
Communication to microcontroller	Made for Arduino	Made for e-health platform - shield required for Arduino	Made for e-health platform - shield required for Arduino	8-pin DIN connection. Cannot find adaptor for Arduino
Ease of programming	Sample Arduino code available	Can develop code	Can develop code	Unable to connect to Arduino, cannot develop code
Sensor placement (location)	Anywhere there are arteries	Finger	Location with good electrical readings	Finger
Reusability	Yes	Yes	No	Yes
Plug-and-play	Yes	Yes	Yes	No
Availability of supply	1	1	1	1

Accelerometer Selection:

Criteria	Weight	SparkFun ADXL377		ST 497-13903-1-ND	
		Rating (-1,0,1)	Weighted Score	Rating (-1,0,1)	Weighted Score
Accuracy	4	0	0	1	4
Continuous	2	0	0	0	0
Durability	2	1	2	1	2
Cost	2	1	2	1	2
Size	4	0	0	1	4
Communication to microcontroller	4	1	4	-1	-4
Ease of programming	5	1	5	-1	-5
Distance	1	0	0	0	0

Reusability	2	0	0	0	0
Plug-and-play	4	1	4	-1	-4
	Total Score	17		-1	
	Rank	1		2	

Scoring Details of Accelerometer Selection:

Criteria	SparkFun ADXL377	ST 497-13903-1-ND
Accuracy	+/- 200g	+/- 400g
Continuous	Yes	Yes
Durability	Same	Same
Cost (w/o shipping and tax)	Same	Same
Size	Larger	Smaller
Communication to microcontroller	Made for Arduino	Requires setup
Ease of programming	Sample Arduino code available	Sample code available
Sensor placement (location)	Same	Same
Reusability	Yes	Yes
Plug-and-play	Yes	No
Availability of supply (# per order)	1	1

Push Button Selection:

Criteria	Weight	<u>On-Off Power Button / Pushbutton Toggle Switch</u>		<u>16mm Illuminated Pushbutton - White Momentary</u>	
		Rating (-1,0,1)	Weighted Score	Rating (-1,0,1)	Weighted Score
Cost	3	1	3	1	3
Size	2	1	2	1	2
Incorporation within a Hard Hat	3	0	0	1	3
Ease of programming	3	1	3	1	3
Additional Features	1	0	0	1	1
Plug-and-play	2	1	2	0	0
Availability of supply (# per order)	1	1	1	1	1
	Total Score	11		13	
	Rank	2		1	

Scoring Details of Push Button Selection:

Criteria	<u>On-Off Power Button / Pushbutton Toggle Switch</u>	<u>16mm Illuminated Pushbutton - White Momentary</u>
Cost w/o shipping	\$1.95	\$1.95
Size	-	-
Incorporation within a Hard Hat	-	Shape and Threading makes it much easier to incorporate into the final unit
Ease of programming	Code is available	Code is available
Additional Features	-	Built in LED to alert when depressed
Plug-and-play	Can be directly plugged into a breadboard	Requires Soldering, but leads can be added much more easily
Availability of supply	Can be purchased in single quantity	Can be purchased in single quantity

Appendix B.1: Solidworks Model

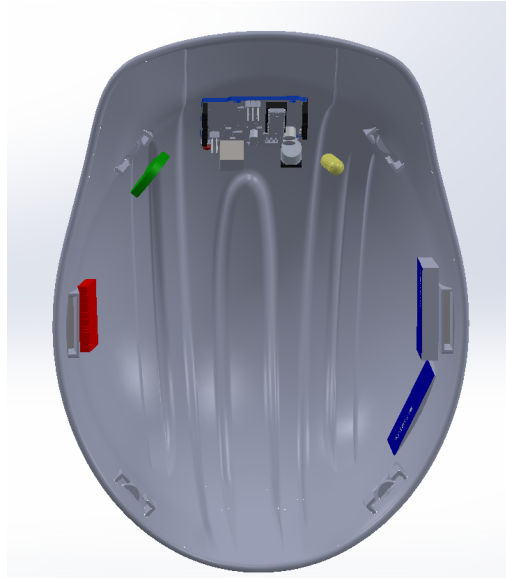


Figure 4. View from bottom, component placement inside the hard hat from left to right: *Accelerometer (red), Pulse Sensor (green), Arduino Board, Thermistor (yellow), and Transmitter/Antenna (blue)*

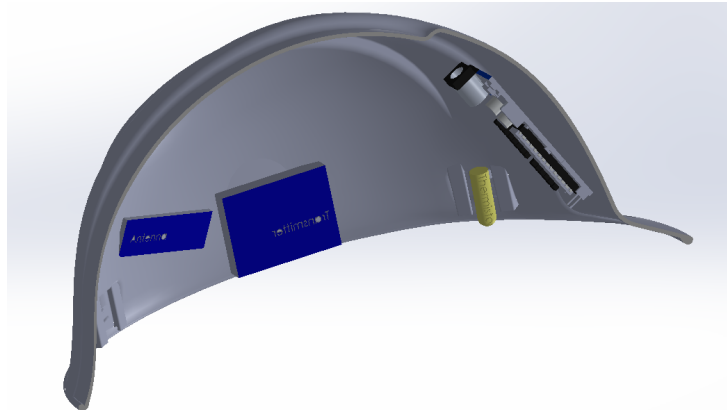


Figure 5. Cutaway view showing thermistor (yellow) and transmitter/antenna (blue) locations

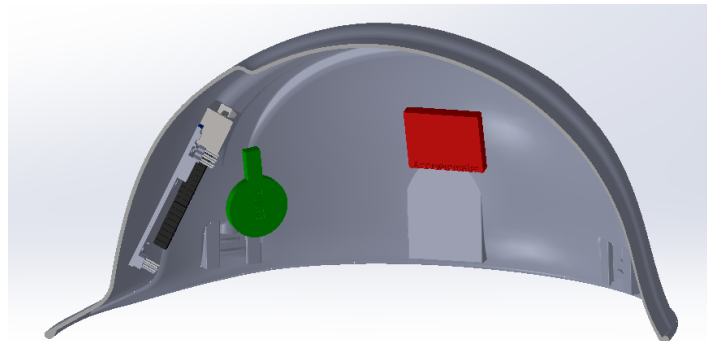


Figure 6. Cutaway view showing pulse sensor (green) and accelerometer (red) locations

Appendix B.2: Circuit Schematic

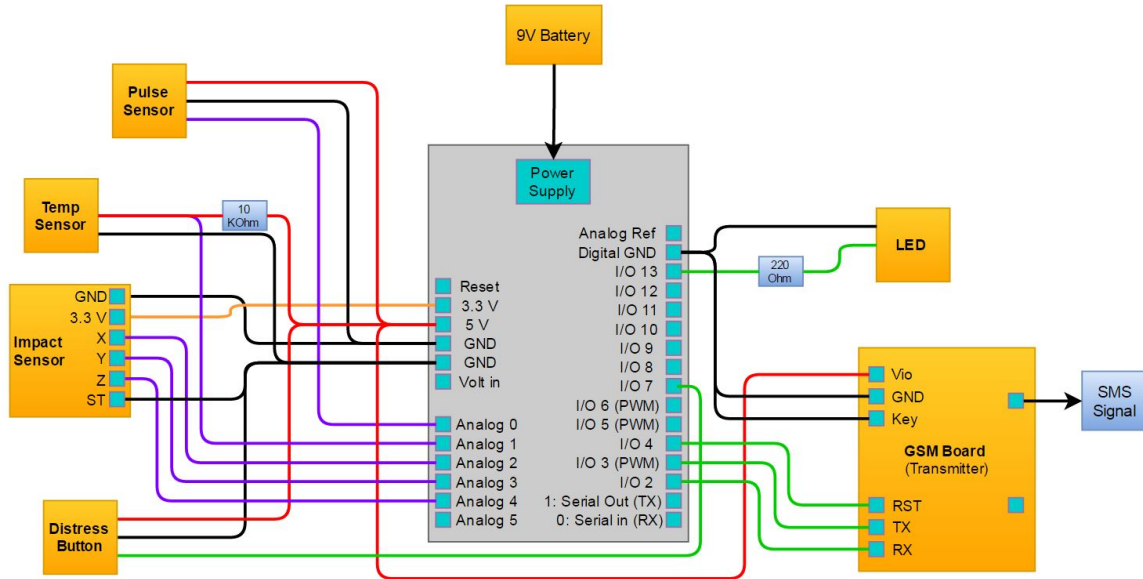


Figure 7. Circuit Schematic

Appendix C.1.1: Arduino Uno Testing Protocol

Arduino Uno Board Test Protocol

Author: Connor Langenderfer

Revision: 0.0

This is a test protocol to evaluate the accuracy of the Arduino Uno for use with the Smart Hard Hat device.

Scope

This test protocol is intended to assess the Arduino Uno board's accuracy and functionality within the Smart Hard Hat design project.

Objective

This testing protocol aims to ensure that the Arduino Uno board used in the Smart Hard Hat device functions in accordance with a predetermined code.

Equipment

- Arduino Uno Board
- Laptop with Arduino software
- Breadboard
- LED
- 200 ohm resistor
- Patch cables
- Arduino sample code (LED)
- Multimeter (Commercial Electric Model: MS8332C)

Procedure

1. A small sample circuit (Arduino LED tutorial) will be built using the Arduino Uno board and breadboard.
2. A sample code (Arduino LED tutorial) will be downloaded to the Uno board and tested to see that the board functions as intended (LEDs turn on).
3. Using a multimeter, measure and record the voltage output for the pin being used to ensure the appropriate 5V or 3.3V as indicated on the board
4. Using a multimeter, measure and record the current coming from the pin being used
5. This can be repeated for all pins that may be used in the final Smart Hard Hat design to ensure their functionality.

Appendix C.1.2: Transmitter Testing Protocol

Transmitter Test Protocol

Author: Charlton Johns

Revision: 0.0

This is a test protocol to evaluate the accuracy and functionality of the FONA 800 GSM Transmitter for use with the Smart Hard Hat device.

Scope

This test is intended to prove the essential functionality and data transmission range of the FONA 800 GSM Transmitter during use.

Objective

The objective of this test protocol is to determine the effectiveness of data transmissions from the FONA 800 GSM Transmitter over a range of distances, obstacles and signals.

Equipment

- FONA 800 Transmitter
- Antenna
- Fully charged battery
- Arduino UNO Microprocessor
- Breadboard
- Laptop with Arduino connecting cable
- Cell Phone

Procedure

1. Connect FONA 800 unit to the Arduino board.
2. Using the Laptop and an adequate code, create a signal message to send.
3. Select the number of whom should receive the message.
4. Send message through the transmitter.
5. Verify receipt of message on cell phone.
6. Repeat steps 4-5 over a variety of distances and terrains.

Appendix C.1.3: Thermistor Testing Protocol

Temperature Sensor Test Protocol

Author: Dominic Conte

Revision: 0.1.1

This is a test protocol to evaluate the accuracy of the temperature sensor during the development of the Smart Hard Hat.

Scope

This test is intended to provide empirical evidence for the continued functionality and accuracy of the Adafruit 10K Precision Epoxy Thermistor - 3950 NTC, and its ability to work within the Smart Hard Hat system.

Objective

To verify the accuracy of the Adafruit 10K Precision Epoxy Thermistor and its ability to work with the Arduino.

Sample Size

Ten (10) measurements will be recorded in each testing setup in order to accurately determine the statistical significance of the data collected.

Equipment

- Adafruit 10K Precision Epoxy Thermistor
- Arduino Uno
- Breadboard
- FONA 800 Transmitter
- Multimeter (Commercial Electric Model: MS8332C)
- Digital Thermometer (Walgreens Flex Tip 2 Second Digital Thermometer, Item No: 354062)

Procedure

1. Verify Resistance

1. Connect the thermistor to the Arduino Uno
2. Place thermistor at temperature sensing location on the body, and allow the reading to stabilize according to the Arduino's output. Record the temperature and measured resistance shown.
3. While maintaining the placement of the thermistor, disconnect it from the Arduino board and measure its resistance using a multimeter.
4. Repeat 10 times
5. Compare the measured resistances to the theoretical resistance of thermistor. (Theoretical Values given here: https://www.adafruit.com/datasheets/103_3950_lookuptable.pdf)

2. Verify Temperature Readings

1. Connect the thermistor to the Arduino Uno

2. Place thermistor at temperature sensing location on the body, and allow the reading to stabilize according to the Arduino's output. Record the temperature, and note the time it takes for the temperature reading to stabilize.
3. Being careful to limit the thermistor's exposure to the outside air, measure the temperature at the same location on the body.
4. Repeat 10 times, waiting a minimum of 1 minute between trials.
5. Compare the measured value of the thermometer to that of the thermistor.

3. Verify Temperature Readings on person while in motion/stationary

1. Connect the thermistor to the Arduino Uno
2. Place thermistor at temperature sensing location on the body, and allow the reading to stabilize according to the Arduino's output. Record the temperature.
3. Once the temperature has stabilized, begin movement at a walking pace and note any fluctuations that occur while in movement.
4. Return to a stationary position, and allow the thermistor to stabilize if necessary.
5. Once the temperature has stabilized, begin movement at a pace of a light jog, again noting any fluctuations in temperature.
6. Repeat steps 2-5 5 times.

4. Verify Signal Transmission

1. Connect the thermistor to the Arduino Uno.
2. Within the Arduino code, set the maximum and minimum thresholds to values that can be easily exceeded and fallen short of, respectively.
3. Using body temperature or an external heat source, exceed the preset value and verify that a signal has been transmitted.
4. Likewise, using cold ambient air, or an object that has been cooled via refrigeration or freezing, allow the thermistor to fall short of its minimum value of temperature sensing, and verify that a signal has been sent.
5. Repeat 10 times for each temperature, allowing adequate time for the thermistor to return to an intermediary temperature.

Appendix C.1.4: Pulse Sensor Testing Protocol

Pulse Sensor Test Protocol

Author: Darcy Fyffe

Revision: 0.1

This is a test protocol to evaluate the accuracy of the Pulse Sensor Amped for use with the Smart Hard Hat device.

Scope

This test is intended to provide empirical evidence for the continued functionality and accuracy of the pulse sensor during use.

Objective

The testing objective is to assess and verify the accuracy of the pulse sensor readings as compared to a standard chest heart rate monitor at varying levels of heart rate activity. Heart rate readings will be collected for resting heart rate, moderate activity heart rate (as simulated by walking), and rapid heart rate (as simulated by walking on an incline).

Sample Size

Ten (10) measurements will be recorded in each testing setup in order to accurately determine the statistical significance of the data collected.

Equipment

- Pulse Sensor Amped
- Chest Heart Rate monitor (Polar FT1 watch and chest monitor)
- Arduino Uno Board
- Laptop with Arduino software
- The UARC treadmill

Procedure

1. Attach pulse sensor and chest heart rate monitor to subject.
2. Ensure all equipment is powered up with proper functionality.
3. Allow subject to sit at rest with no activity for at least two minutes to achieve an accurate resting heart rate.
4. While the subject is at rest (sitting and motionless) begin heart rate measurements. Record heart rate every 10 seconds for both pulse sensor monitors for a total of 10 measurements.
5. Once the resting heart rate level has been completed, allow the subject to walk in place to elevate the heart rate. Once the heart rate has stabilized, begin heart rate measurements. Record heart rate every 10 seconds for both pulse sensor monitors for a total of 10 measurements.
6. Once the walking heart rate level has been completed, allow the subject to walk on a treadmill at an incline elevate heart rate. Once the heart rate has stabilized, begin heart rate measurements. Record heart rate every 10 seconds for both pulse sensor monitors for a total of 10 measurements.
7. Assess accuracy of the sensor via statistical analysis.

Appendix C.1.5: Accelerometer Testing Protocol

Accelerometer Test Protocol

Author: Benjamin DeShon

Revision: 0.0

This is a test protocol to evaluate the accuracy of the ADXL377 accelerometer for use with the Smart Hard Hat device.

Scope

This test is intended to provide empirical evidence for the continued functionality and accuracy of the ADXL377 accelerometer during use.

Objective

The objective of this test protocol is to determine the accuracy of impact readings from the ADXL377 accelerometer over a range of impact forces.

Sample Size

Ten (10) measurements will be recorded in each testing setup in order to accurately determine the statistical significance of the data collected.

Equipment

- ADXL377 accelerometer
- Arduino UNO Microprocessor
- Breadboard
- Laptop with Arduino software

Procedure

Verify accuracy while stationary

1. Connect ADXL377 unit to the Arduino board.
2. Ensuring that the ADXL377 is seated properly and is on a flat plane, open up the Monitor.
3. Ensure that the Monitor shows the Z-axis at around -1.00g (due to the large range of the accelerometer, some variance is accepted.)
4. Tilt the breadboard with accelerometer so the X-axis is pointing down (indicated on the ADXL377) and repeat.
5. Tilt the breadboard with accelerometer so the Y-axis is pointing down (indicated on the ADXL377) and repeat.
6. Repeat steps 3-5 a total of ten times.

Verify accuracy with impact

1. Connect ADXL377 to the Arduino board and boot Arduino software.
2. Attach board and accelerometer to rail car of motion system using tape, ensuring all connections are tight and board is securely fastened to car.
3. Start recording data in motion interface.

4. Push the car manually down the track, then stop the car using your hand. Ensure hand does not block the path of the motion sensors in front of the car.
5. Stop recording data in motion interface.
6. Record the acceleration values at the moment the car is stopped on both the Arduino Serial Monitor and the motion software.
7. Repeat steps 3-6 for a total of ten trials.

Appendix C.1.6: Push Button Testing Protocol

Push Button Test Protocol

Author: Dominic Conte

Revision: 0.0

This is a test protocol to evaluate the ability of the Adafruit 16mm Illuminated Pushbutton to communicate with the FONA 800 transmitter during the development of the Smart Hard Hat.

Scope

This test is intended to verify of the ability of our push button (Adafruit 16mm Illuminated Pushbutton - White Momentary) to communicate to our transmitter within the Smart Hard Hat system.

Objective

To verify the accuracy of the Adafruit 16mm Illuminated Pushbutton - White Momentary and its ability to communicate a signal through the Arduino.

Sample Size

Ten (10) measurements will be recorded in each testing setup in order to verify the consistency of the push button to function as intended.

Equipment

- Adafruit 16mm Illuminated Pushbutton - White Momentary
- Arduino Uno
- Breadboard
- FONA 800 Transmitter

Procedure

Verify Communicative Ability

1. Connect the push button and transmitter to the Arduino Uno Microcontroller.
2. Depress push button to its lowest point.
3. Verify that a signal has been sent to the transmitter
4. Repeat until 10 signals have been accurately transmitted

Appendix C.2.1: Arduino Uno Test Results

Arduino Uno Test Results

Test Time: Saturday, February 6, 2016

Test Location: 80 North Portage Path, Akron, OH

Tested by: Connor Langenderfer

Reason: This document explains the results of the testing done on the Arduino Uno Microcontroller for the Smart Hard Hat.

Procedure: See Arduino Uno Testing Protocol

Results:

Table 1. Board Voltage

Board	Multimeter Reading (V)
5V pin	5.06
3.3V pin	3.328

Table 2: Digital Pin Test Results

Pin	LED Blink?	Status
0	Verified	Operational
1	Verified	Operational
2	Verified	Operational
3	Verified	Operational
4	Verified	Operational
5	Verified	Operational
6	Verified	Operational
7	Verified	Operational
8	Verified	Operational
9	Verified	Operational
10	Verified	Operational
11	Verified	Operational
12	Verified	Operational
13	Verified	Operational

Table 3: Analog Pin Test Results

Pin	LED Fade?	Status
A0	Verified	Operational
A1	Verified	Operational
A2	Verified	Operational
A3	Verified	Operational
A4	Verified	Operational
A5	Verified	Operational

Conclusion: The Arduino Uno is functional and has passed all metrics required for the Smart Hard Hat.

Appendix C.2.2: Transmitter Test Results

Transmitter Test Results

Test Time: Saturday, February 6, 2016

Test Location: 80 North Portage Path, Akron, OH

Tested by: Charlton Johns

Reason: This document explains the results of the testing done on the GSM Board Adafruit FONA 800 as a transmitter for the Smart Hard Hat.

Procedure: See Transmitter Testing Protocol

Results:

Table 1. Test message distance results

Message	Distance	Received
1	2 feet	Confirmed
2	6.4 miles	Confirmed
3	3.2 miles	Confirmed
4	4.7 miles	Confirmed
5	2467 miles	Confirmed

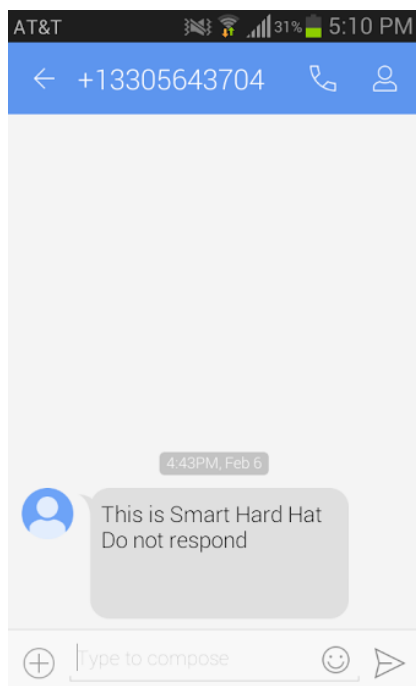


Figure 1: How the test alerts appear to the user

Conclusion: The FONA 800 Transmitter works well and has passed all metrics required for the Smart Hard Hat.

Appendix C.2.3: Thermistor Test Results

Thermistor Test Results

Test Time: Sunday, January 31 & Saturday, February 6, 2016

Test Location: 80 North Portage Path, Akron, OH

Tested by: Dominic Conte, Darcy Fyffe, Charlton Johns and Connor Langenderfer

Reason: This document explains the results of the testing done on the Adafruit 10K Precision Epoxy Thermistor - 3950 NTC to determine its accuracy and ability to function with Arduino.

Procedure: See Temperature Sensor Test Protocol (Sections 1 & 2)

Results:

Verify Resistance

Following the steps from the Temperature Sensor Test Protocol, the thermistor resistance displayed by the Arduino software was compared to the resistance values measured by the multimeter to ensure that the displayed values were accurate. The results of this test are displayed in Table 1 below.

Table 1. Test results for verification of resistance

Sample #	Measured Thermistor Temperature (°F)	Measured Resistance, Arduino (Ω)	Multimeter Resistance (Ω)	Theoretical Resistance (Ω)	Difference from Arduino (Ω)	Difference from Multimeter (Ω)
1	97.682	6115.1	6150	6149	33.9	-1
2	98.312	6029.46	6070	6061	31.54	-9
3	98.6	5989.37	6010	6020	30.63	10
4	98.7	5969.4	5990	6008	38.6	18
5	98.888	5944.51	5930	5981	36.49	51
Average	98.4364	6009.568	6030	6043.8	34.232	13.8
St Dev	0.47	66.68	83.67	65.49	3.34	23.21

Statistical analysis using a two-sample t test in MATLAB calculated a P-value of 0.6812 (>0.05). This indicates that the difference in means for the measured resistance and multimeter resistance are statistically insignificant at a 95% confidence interval.

Our results showed that while the multimeter had closer overall averages to the theoretical resistance, the Arduino's measurements were much more consistently deviated from the theoretical (Standard Deviation of 23.21 vs 3.35 respectively). So while the multimeter may be more accurate, our resistance values as measured through the Arduino are more precise.

Verify Temperature

Following the steps from the Temperature Sensor Test Protocol, the thermistor temperatures displayed by the Arduino software were compared to the temperature values measured by the digital thermometer to ensure that the displayed values were accurate. Tables 2,3 and 4 below display the measured results.

Table 2. Test 1 results for verification of temperature at axilla

Sample #	Thermometer Temp (°F)	Thermistor Temp (°F)	Difference (°F)
1	97.9	96.71	1.19

2	98.7	97.18	1.52
3	98.1	97.6	0.5
4	98.2	97.58	0.62
5	98.1	97.7	0.4
Average	98.2	97.354	0.846
St Dev	0.3	0.411	0.485

Table 3. Test 2 results for verification of temperature at axilla

Sample #	Thermometer Temp (°F)	Thermistor Temp (°F)	Difference (°F)
1	98.7	96.998	1.702
2	98.3	97.178	1.122
3	98.3	97.718	0.582
4	98.4	97.43	0.97
5	98.5	97.502	0.998
6	98.5	97.574	0.926
7	98.5	97.718	0.782
8	98.4	97.394	1.006
9	98.4	97.142	1.258
10	98.3	96.998	1.302
Average	98.43	97.3652	1.0648
St Dev	0.125	0.273	0.308

Table 4. Test 3 results for verification of temperature at temporal artery

Sample #	Thermometer Temp (°F)	Thermistor Temp (°F)	Difference (°F)
1	98	96.53	1.47
2	97.6	96.782	0.818
3	97.5	96.746	0.754
4	97.4	96.638	0.762
5	97.1	96.566	0.534
6	97.7	96.422	1.278
7	97.7	96.746	0.954
8	97.9	96.566	1.334
9	97.8	96.53	1.27
10	96.7	96.35	0.35
Average	97.54	96.5876	0.9524
St Dev	0.392	0.142	0.373

(NB: For temperature measurements at the temporal artery, the thermistor was held in place by an elastic wool cap (similar to the hard hat suspension's elastic band) and a finger was held in place over the

temporal artery to assure measurements were taken in the same place for both the thermometer and thermistor.)

Table 5. Temperature test P-Values for Paired t-test at 95% Confidence

Test #	P-Values
1	0.0064
2	6.28×10^{-8}
3	1.455×10^{-6}

Statistical analysis using a two-sample t test in MATLAB calculated a P-value of less than 0.05 for all three temperature tests. This indicates that the difference in means for the thermistor temperatures and the digital thermometer temperatures are statistically significant at a 95% confidence interval.

Conclusion:

With regards to temperature sensing, the temperature measurement through the thermistor is approximately 1 degree lower on average than the equivalent measurement through a digital thermometer. This is likely a result of the departure from the theoretical resistance of the thermistor compared to the measured value as shown above. As such, we will have to either adjust our code to scale to the correct temperature, or lower our minimum/maximum thresholds by ~one degree in order to make up for this discrepancy.

Appendix C.2.4: Pulse Sensor Test Results

Pulse Sensor Test Results

Test Time: 10:30 am Monday, March 7

Test Location: The University of Akron Recreational Center

Tested by: Dom Conte, Darcy Fyffe, Charlton Johns, Connor Langenderfer

Reason: This document explains the results of the testing done on the Pulse Sensor Amped sensor to determine its accuracy and functionality.

Procedure: See Pulse Sensor Testing Protocol

Results:

Following the steps from the Pulse Sensor Test Protocol, the readings from the Polar FT1 heart rate chest monitor were compared to the Pulse Sensor Amped readings. The results of this test showed that at varying levels of physical activity, the subject displayed an average resting heart rate of 103.7 7.54 bpm and 101.2 4.34 bpm, an average walking heart rate of 133.1 8.39 bpm and 1276.02 bpm, and an average inclined walking heart rate of 169.58.4 bpm 166.18.5 bpm for the Pulse Sensor Amped and Polar FT1 respectively (see Table 1).

Table 1. Heart Rate Results

Activity Level	Sample #	Pulse Reading (bpm)	
		Pulse Sensor Amped	Polar FT1
Rest	1	90	95
	2	109	107
	3	115	100
	4	97	99
	5	108	102
	6	99	98
	7	108	100
	8	102	101
	9	99	100
	10	110	110
	Average	103.7	101.2
	St Dev	7.54	4.34
Walking in Place	1	131	136
	2	150	131
	3	135	125
	4	120	113
	5	141	127

	6	129	132
	7	138	126
	8	132	126
	9	128	126
	10	127	128
	Average	133.1	127
	St Dev	8.39	6.02
Walking on Incline	1	148	149
	2	155	153
	3	159	159
	4	172	170
	5	164	166
	6	169	172
	7	171	172
	8	172	171
	9	169	170
	10	172	171
	11	173	174
	Average	165.9	166.1
	St Dev	8.4	8.5

Statistical evaluation using a two-sample t-test for each of the physical activity levels calculated P-values greater than 0.05 for each activity level (See Table 2). This indicates that the results from the Pulse Sensor Amped and the Polar FT1 monitors are statistically equal.

Table 2. P Values for Physical Activity Levels

Activity Level	P-Values
Rest	0.3787
Walk	0.0797
Incline	0.9604

Conclusion: We can conclude from our testing that on average, the Pulse Sensor Amped (PPG) records statistically equal values to that of a standard (ECG) chest heart rate monitor. However, we did notice a high level of variance during the pulse sensor readings. The sensor would stabilize, jump to a heart rate much higher, then down to a heart rate much lower on a relatively frequent basis. This may be due to motion artifacts caused by the movement of the wearer, or light interference from the room. We will use this information to adjust the threshold of the Arduino Code to include a statement that the elevated heart rate must be sustained from at least 30 seconds to ensure that the measured heart rate is not a fluctuation as a result of movement or light interference.

Appendix C.2.5: Accelerometer Test Results

Accelerometer Test Results

Test Time: 1:45 pm Sunday, February 21 and

Test Location: 80 North Portage Path, Akron, OH

Tested by: Ben DeShon, Darcy Fyffe

Reason: This document explains the results of the testing done on the

Procedure: See Impact Sensor/Accelerometer Testing Protocol

Results:

Verify Accuracy While Stationary

Following the steps from the Impact Sensor/Accelerometer Test Protocol, the gravitational reading displayed by the Arduino circuit was compared to the actual value of gravity (1.0 g). The results of this test are displayed in Table 1 below.

Table 1. Stationary Accelerometer Measurements

Sample #	Force Reading (g)		
	X Axis	Y Axis	Z Axis
1	1.5	0.9	0.9
2	1.5	0.9	0.9
3	1.5	0.9	0.9
4	1.5	0.9	0.9
5	1.5	0.9	0.9
6	1.5	0.9	0.9
7	1.5	0.9	0.9
8	1.5	0.9	0.9
9	1.5	0.9	0.9
10	1.5	0.9	0.9
Average	1.5	0.9	0.9
St Dev	0	0	0

Due to the lack of variance between readings, statistical analysis would not provide us with any new information. The means of each axis are all statistically different from the standard value of 1.0 g for the force of gravity.

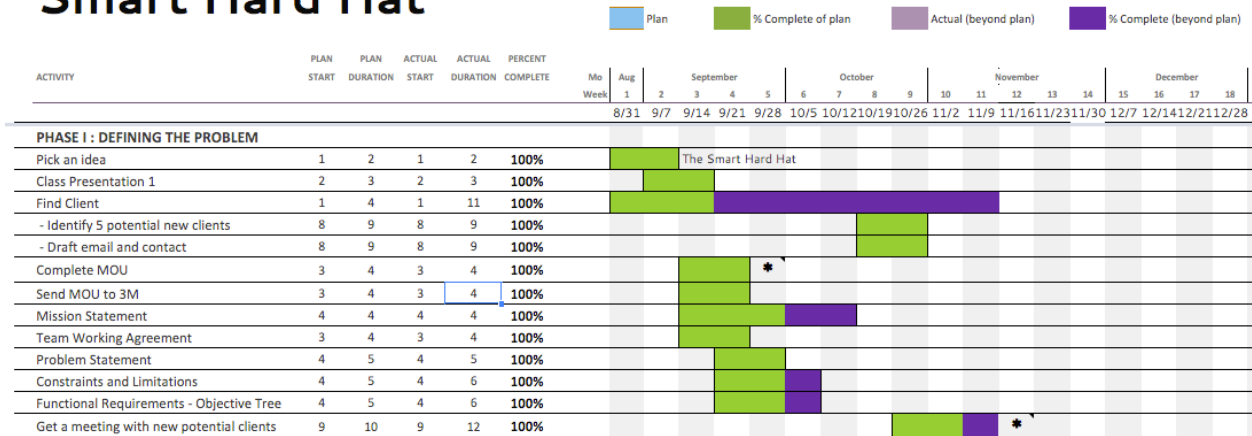
Conclusion: We can conclude from this testing that the accelerometer is functional. Due to the lack of impact, variance was expected at the 1g level. Going forward we plan to test the sensor with measurable impacts to monitor its accuracy

Appendix D.1: Gantt Chart

Note: Full Excel file submitted in addition to report

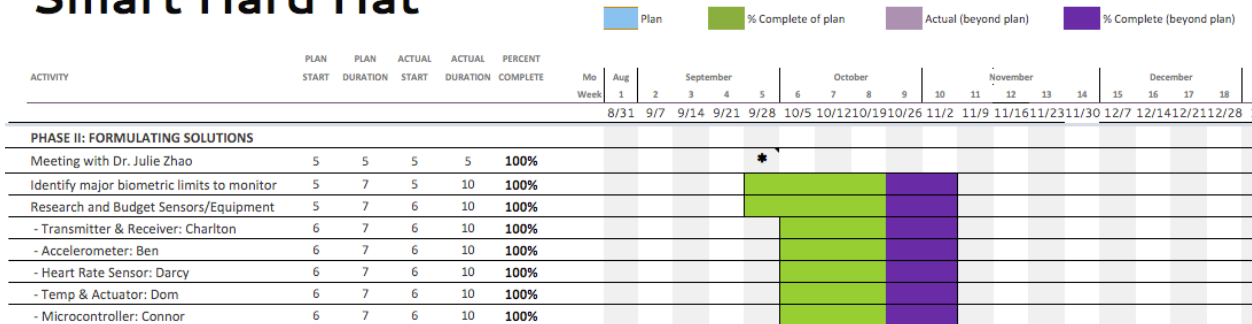
Phase I

Smart Hard Hat

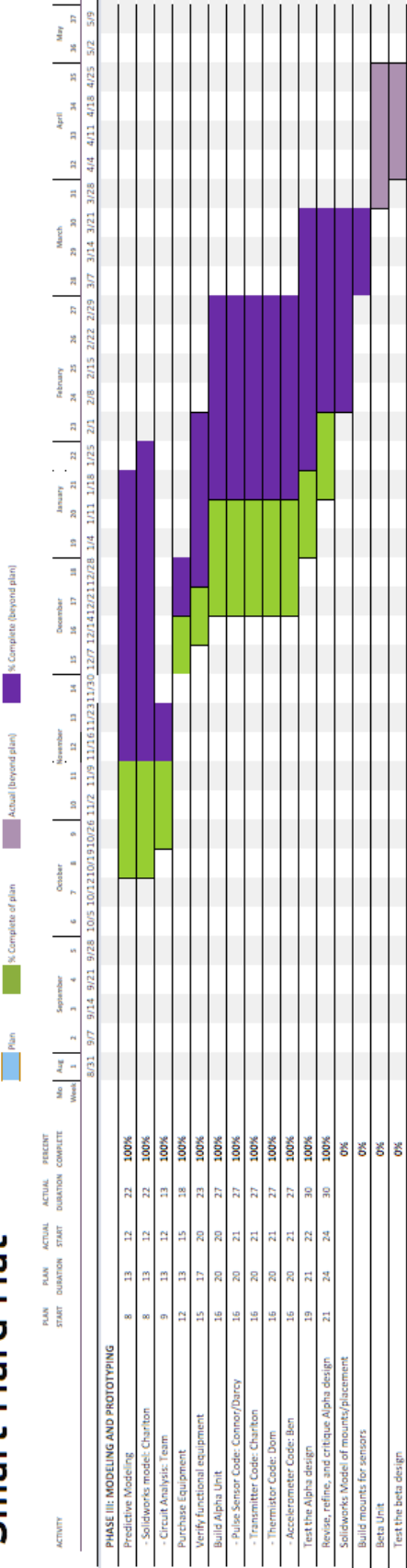


Phase II

Smart Hard Hat



Smart Hard Hat



Appendix E.1: Budget

Member	Product	Qty	Price	Total (with tax & shipping)
Ben DeShon	SparkFun ADXL377 Triple Axis Accelerometer Breakout	1	\$24.95	\$29.08
	MOD ACCELEROMETER 3AXIS 16LLGA	1	\$10.20	\$22.82
	Mutual 50215 Polyethylene 6-Point Ratchet Suspension Hard Hat, White	1	\$10.23	\$10.92
Dominic Conte	10k Precision Epoxy Thermistor	2	\$8.00	\$17.12
	Auto ranging digital multimeter	1	\$36.97	\$39.47
	Digital Flx tip 2 sec thermometer	1	\$15.99	\$15.99
	1 x 16mm Illuminated Pushbutton - White Momentary	1	\$1.95	\$11.50
Darcy Fyffe	Pulse Sensor Amped	1	\$25.00	\$34.12
	OfficeMax A-Z buff dividers, preprinted tabs	1	\$6.99	
	Avery Ready Index, Table of Contents dividers, 1-12 tab	1	\$5.79	\$13.64
Charlton Johns	Slim Sticker-type GSM/Cellular Quad-band Antenna	1	\$2.95	
	Adafruit FONA - mini cellular GSM Breakout uFL Version	1	\$39.95	\$52.02
	Lithium Ion Polymer Battery - 3.7v 500mA	1	\$7.95	
	USB cable - A/MicroB (3ft)	1	\$2.95	\$20.47
	Flexible Prototype Board	1	\$7.50	\$16.99
	T-Mobile Sim Card	1	\$23.50	\$23.50
Connor Langenderfer	Programming Arduino Getting Started with Sketches, Monk, Simon	1	\$8.08	\$13.95
	16Hz Electronics Project Starter Kit	1	\$17.30	\$17.30
	Arduino Uno Rev 3	1	\$19.95	\$26.01
	RGB 3-Color LED Module for Arduino	1	\$0.99	\$1.32
TOTAL SPENT				\$366.22
Budget Limit				\$500.00
TOTAL AVAILABLE				\$133.78
% of Budget Used				73.24%