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Wireless impact sensing headband - W.I.S.H.

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Date: June 11, 2014

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ENTITLED

W.I.S.H. – Wireless Impact Sensing Headband

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&
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WIRELESS IMPACT SENSING HEADBAND
W.I.S.H.

by

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SENIOR DESIGN PROJECT REPORT

Submitted in partial fulfillment of the requirements
for the degree of
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WIRELESS IMPACT SENSING HEADBAND - W.I.S.H.

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ABSTRACT

The prevalence of undiagnosed head injuries in the athletic world, and their associated health risks, is too great to ignore. This is especially true in non-helmeted sports where the availability of impact monitoring technologies is few and far between. In this paper, we discuss our wireless impact sensing headband technology that aids in the awareness and detection of potential concussions, from inception through design completion. Through the use of a custom-built validation system capable of simulating impact collisions, along with a series of experiments and revisions, our team was able to build a device that can sense and transmit data throughout the majority of the impact range of standard concussions. This system has the potential to help millions of athletes around the world be much better prepared in the event of a potentially life-threatening head impact. However, while our system is able to accurately detect and transmit impact data in real time, we found that additions such as the ability to sample at a much higher rate than experimented with, a more ergonomic design, and a lightweight, durable enclosure would be needed in order for our product to be a viable mass-market competitor. Although the product is not ready for the mass market as of today, it will be a vital part to larger systems used for predictive analytics and more innovative and robust athletic game strategy.

Keywords: Concussions, Impact Sensing, Predictive Analytics, Real-Time

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1. INTRODUCTION

1.1 Background

The Centers for Disease Control and Prevention estimate that over 3.2 million concussions are incurred yearly in the USA (West). In 2009, up to 53% of concussions in high school football went unreported (Bartsch). A concussion is a term used to describe a mild traumatic brain injury which can be induced by blunt force or any other violent movement of the head and neck. This type of trauma typically presents itself in the form of lowered cognitive function such as dizziness, loss of balance, and headaches (McCrory).

According to the American Association of Neurological Surgeons, almost 447,000 sports-related head trauma injuries occurred in 2009. This number increased by 95,000 from 2008. The eight activities with the greatest amount of head injuries are listed below in Table 1-1, with the number of injuries being specific to overall head injuries, rather than just the brain.

Table 1-1: A list of the eight activities with the greatest amount of head injuries in 2009. (AANS)

Activity	**Number of Injuries**
Cycling	85,389
Football	46,948
Baseball	38,394
Basketball	34,692
Water Sports	28,716
Powered Recreational Vehicles	26,606
Soccer	24,184
Skateboarding	23,114

Figure 1-1 below compares the number of concussions per 1000 athletic exposures in

NCAA football between the years 2004 and 2012. Although though there is no significant upward trend, it is important to realize that no serious efforts have been made to tangibly address the issue in the past ten years. This is contrary to other safety systems such as the automotive industry and is indicative of a lack of interest in player's health and safety.

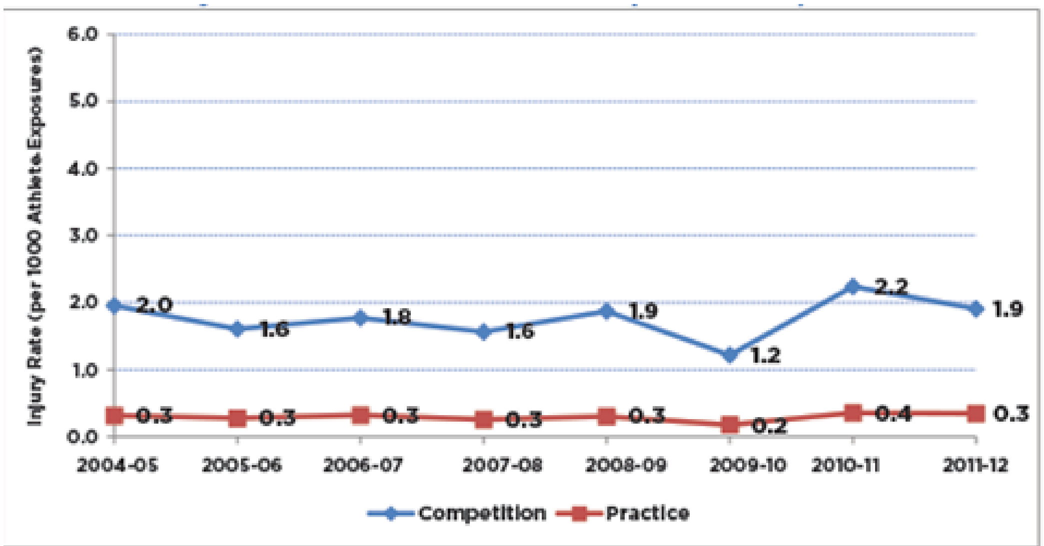

Figure 1-1: A comparison between the average number of reported concussions per 1000 athletic exposures in NCAA football between 2004 and 2012 in competition and practice. (NCAA)

Unfortunately, the current means of actively protecting athletes is mostly outdated and can actually exacerbate the risks. In sports like football, because players effectively wear armor, opponents tend to be more aggressive and consequently hit other players harder and more often. These larger impact forces, and increased number of repetitions, increase the risk of a traumatic brain injury.

According to an interview conducted by our team of Dr. Odette Harris, the Director of Brain Injury, Department of Neurosurgery at Stanford Medical Center, harm associated with repeated concussions can be compounded. Therefore serious and permanent brain damage is much more likely to occur when subjected to multiple concussions without time to heal. Also, the complex medical nature of a concussion entails that there is no single conclusive test that can be used on a playing field to determine the severity of a head injury. Therefore, the difficulty in diagnosing a concussion, in conjunction with the dangers associated with recurrent concussions, poses an alarming issue in the athletic world.

Currently, the only method of detecting concussions on the field is by physical inspection of the player or athlete. However, this first requires that people notice when someone falls or is hit harder than normal. This is not always easy, and hard hits are often overlooked in the action of the moment. While products do exist that actively monitor potential trauma-inducing strikes, they are part of an emerging market, meaning they are expensive, inconvenient, or both. Worse yet, according to the Co-Director of OSU Sports Medicine's Movement Analysis & Performance research program, Dr. James Onate, there are no affordable products specifically aimed at youth athletes where monitoring concussions and other mild Traumatic Brain Injuries, or mTBIs, are a primary concern.

In 2012, the 4th International Conference on Concussion in Sport was held in Zurich, Switzerland. At this conference, medical professionals and specialists in the field of head trauma from all over the world convened about the state of concussions in today's athletic community. In their published consensus statement, the group outlined the current and best accepted practices for recovery after suffering a concussion. The major facets of proper concussion management can be explained by the "Return To Play", or RTP, paradigm, which applies to all athletes regardless of their level of participation. RTP explains that under no circumstances should the concussed athlete return to play on the same day of the injury. In addition, the athletes should take a gradual return to their academic and social activities until they can demonstrate proper cognitive and physical function (McCrory).

The conference also agreed that from a medical standpoint, a detailed history of prior concussions is essential. This allows for medical professionals to identify those in a high risk category and educate them on preventative measures. The consensus statement also noted that concussion history as accounted by teammates or coaches is frequently unreliable, and that for a proper medical evaluation, the history should include more than just how many concussions, symptoms and recovery time (McCrory).

1.2 Problem Statement

The prevalence of undiagnosed head injuries in the athletic world, and their associated health risks, is too great to ignore. This is especially true in non-helmeted sports where the availability of monitoring technologies is few and far between. Mild head traumas, also known as concussions, are especially damaging to youth and their developing minds. The goal of this project was to create a head impact monitoring system that aids in the awareness and detection of potential concussions. The system would be able to detect a wide range of impacts and alert the athlete of its severity. The end product would be affordable, comfortable, and easy to use. The sensor system is part of a larger safety system, which wirelessly connects with a smartphone or tablet for data recording and processing. By integrating the head mounted sensors into this system, valuable medical information of a whole team is monitored and recorded for a better diagnosis by a medical professional.

To ensure the effectiveness of the product, a testing rig capable of simulating high acceleration impacts was required in order to verify and validate the data obtained from the sensor system.

Our objectives for success included designing a wireless headband that measures severe accelerations of the head, warning athlete of potential concussion after 35-150 g of acceleration. In addition, developing a mechanical test system that simulates traumatic forces to the head. This included a model human head and neck which performs similarly to real head and neck and a robust and safe testing platform capable of consistently simulating impacts between 35-150 g. Finally, the system must display data from the headband in real time. Through a robust series of testing and system revisions, we were able to successfully validate the functionality of our wireless impact sensing headband device. The device was able to accurately sense, transmit, and process impact data through the range of impacts commonly found to cause concussions.

2. PROJECT OVERVIEW

A description of the project from the system design, testing procedures, and team structure used to progress through and complete the project.

2.1 System-Level Overview

The overall system structure is designed for an athlete equipped with the wireless impact sensing headband, which may either connect to a coach, parent, or trainer on the sidelines through a computer or smartphone-based user interface. A basic illustration of this system can be found below in Figure 2.1-1. When the sensors in the headband detect an acceleration of 70 g or greater, the headband will communicate with its paired phone or tablet. The receiving module will display a warning on the paired phone, computer or tablet that the athlete has suffered a severe impact, has a high probability of a concussion, and should seek medical attention.

Figure 2.1-1: System Physical User Layout

2.2 Subsystem Breakdown

The subsystem breakdown of the project is shown in Figure 2.2-1 and dissects each part of the system into its functional attributes. Because the system relies on wireless capability, each major subsystem will require a radio to interact with the other subsystems.

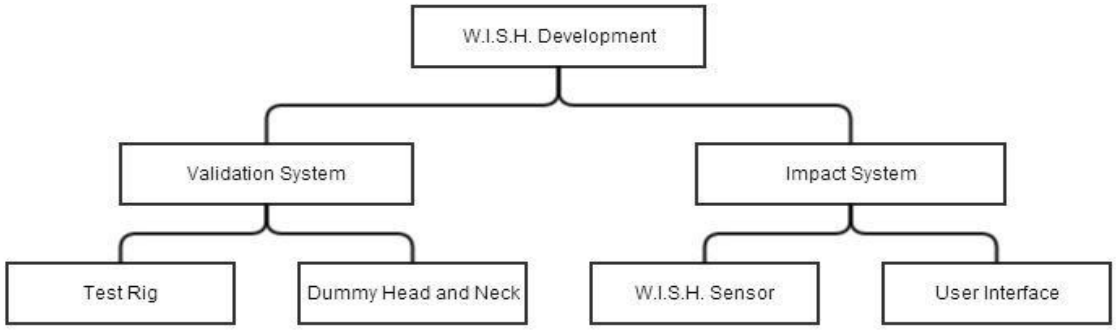

Figure 2.2-1: Subsystem Breakdown

2.2.1 Headband

The headband collects head impact data via an accelerometer and processes and interprets that data through the use of microcontrollers and analog to digital converters. The headband will then communicate with the smartphone or tablet for further analysis by radio. If the collected data falls within a certain threshold, then the athlete will be alerted.

2.2.2 Smartphone

The headband will be primarily connected to a smartphone for proper interpretation and interaction. Therefore, the smartphone will be the gateway to the system, allowing the user to access the results via a phone application.

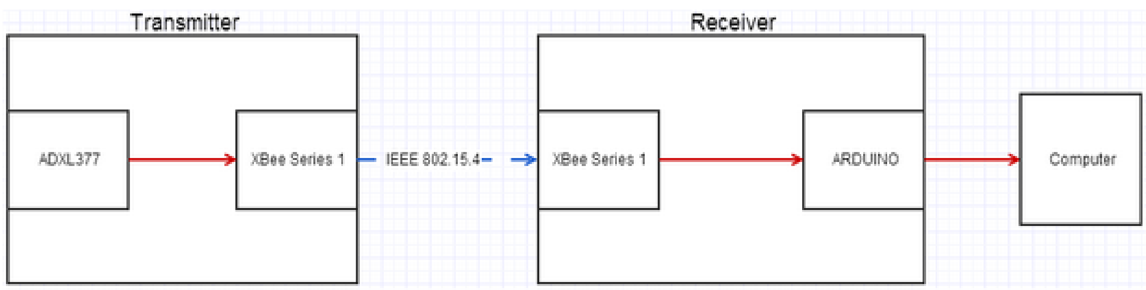

Figure 2.2.2-1: System Level Sketch

2.2.3 Testing System

This subsystem is an integral part of the completed project allowing verification of the accuracy and integrity of the headband. The testing system consisted of two major components, a drop tower and a head and neck assembly. The drop tower was required to be able to consistently simulate 35-150 g impacts. A head and neck assembly was required to simulate a real human head and neck, so that it can wear both the headband as well a truth data accelerometer. The impact data transmitted from the headband's sensors will be cross-checked with truth data collected from calibrated sensors within the test dummy head.

2.3 Customer Needs

Several customer surveys and interviews were conducted during preliminary research. Respondents included Santa Clara University athletes, medical professionals, impact test engineers, sports coaches, sports team owners, and parents.

After reviewing the data, several things became clear:

- Concussions are a very complex phenomena, and their potential consequences are not fully known by most athletes;
- The system is particularly well suited for non-helmeted sports, and high demand exists;
- Players will reject the technology unless it is cheap, unobtrusive, and aesthetically pleasing.

Regarding the first point, a common issue inferred from the customer feedback was that many athletes do not recognize the severity of concussions and the long-term effects caused by repeated head injuries.

A simple survey was conducted among 150 SCU student athletes, who were first asked if they had ever suffered a concussion; the students were then asked to what degree they are concerned with suffering a concussion. The results of this survey can be found below in Figure 2.3-1 and 2.3-2. These two graphs illustrate that many athletes do not feel concerned with head injuries until they see the effects first hand. After a person has had a concussion, his/her perceived risk assessment increases.

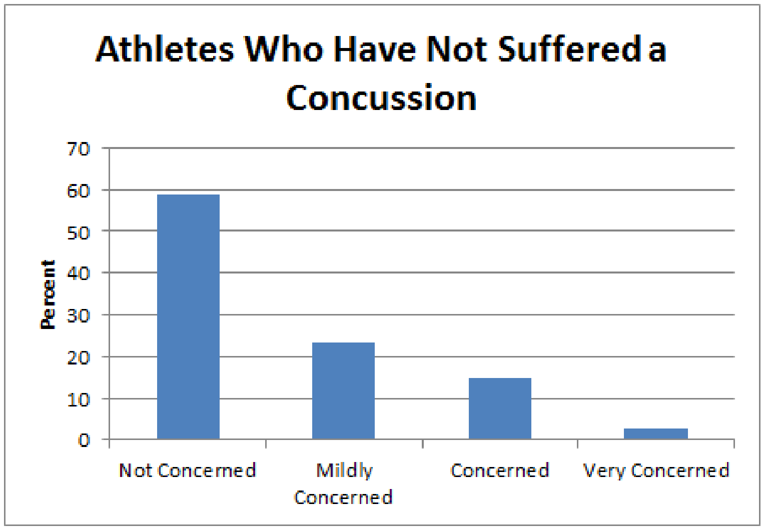

Figure 2.3-1: SCU athletes who have never suffered a concussion and their level of concern about concussion risk.

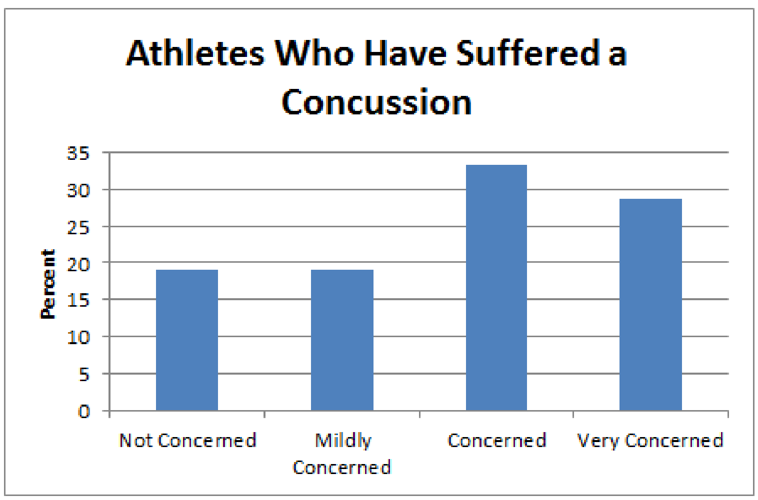

Figure 2.3-2: SCU athletes who have previously been concussed and their level of concern about concussion risk.

Figure 2.3-1 and 2.3-2 represent a fundamental problem in athletics: those who have not yet suffered a concussion do not understand the full extent of its risk to the same degree that those who have.

2.4 System Requirements

The principle of safety is integral our project; as such, the success of our project was defined by the following requirements. The headband must be able to accurately and consistently measure impact forces and their directions, across a range of 0 to 100 g. In addition, it must be durable enough to withstand at least a year's worth of regular usage. This means that the headband should survive 2 "severe" impacts (greater than 70 g), 10 "high" impacts (in between 35 and 70g), and 100 "moderate" impacts (less than 35 g). The headband must also be waterproof to ASTM IPX-8 standards, or protected against water at a depth of below 1 meter. The goal market price must be at or below $100 making this product affordable for our target demographic. A smartphone or tablet interface would allow it to be easy to use through an application

The requirements for the testing system are just as important to adhere to. The impact test rig must be capable of consistently generating a range of accelerations between 20-150 g. In addition, it must be able to simulate a variety of impact "types" such as head on, oblique, etc. Lastly, the head and neck assembly must perform similar to requirements for a standard 50th percentile male crash test dummy.

2.5 Physical Use of Device:

As a finalized and completed system W.I.S.H. will consist of a headband, with a pocket for the wireless sensor, and a small radio receiver for a smartphone, tablet, or laptop. The headband will be flexible and stretchable and similar to that of a common sweatband in use by athletes today. However, this headband will include a pocketed space for which the W.I.S.H. sensor can be easily inserted or removed for washing and/or charging. The wireless receiver will be a small plug with either a USB micro or Apple Lightning connector depending on what the user ordered.

The system will work once the user installs the sensor into the headband, wears it, and the receiver is connected to a smartphone, or tablet, and the app run. For a sports game the typical recommended setup would for a coach, parent, or athletic medical personnel monitor the phone or tablet from the sidelines. During use the system will automatically switch from off to a standby mode when in motion, such as when a player wears the headband. On standby mode the headband will constantly monitor g forces on the player during the course of a game until it detects a sufficiently large blow. If the wearer is subjected to a large blow (greater than 70 g) the sensor will transmit its collected data to the W.I.S.H. receiver attached to a smartphone or tablet on the sidelines. Once collected, the smartphone/tablet will then issue a visual, audio, and vibratory warning with the player's information and trauma risk potential. In this way the player can then be pulled from the field, tested by a medical professional for a concussion, and allowed to properly heal. Additionally, information on each player provided by the W.I.S.H. system will be stored and analyzed by the smartphone/tablet. This collection of impact/injury history can be used to track a player's overall health and allows coaches, parents, and medical professionals to better care for their athletes.

2.6 Benchmarking Results

There are existing products either in development or on the market which also attempt to provide a solution for the issues suffered by athletes due to head injuries, examples include the Reebok CHECKLIGHT and the X2 Biosystem. These devices do not prevent concussions, nor do they diagnose them; these are tools used to assist in the detection of a concussion, so the athlete can seek professional help. However, they are relatively expensive, do not allow the user to track data in real time, and many cannot be used outside of helmeted sports. The development of W.I.S.H. required extensive review and comparison of the existing products.

2.6.1 Reebok CHECKLIGHT:

The Reebok CHECKLIGHT system is expensive ($150), making it less desirable for an amateur athlete. The system, as seen in Figure 2.6.1-1, is a skull cap, primarily designed to be worn under a helmet. Because of this, it cannot be properly used in sports that do not use helmets and has been poorly received due to its size and shape.

In addition, the CHECKLIGHT does not transmit data. Instead, it relies on a LED interface showing green when it is on, yellow as a warning, and red after a potentially dangerous impact. This system gives sideline trainers and medics a quick check to see if the player should be examined further or taken out of the game for the day. The trainers are then able to analyze the amount of impacts a player has received, and estimate the severity of the data after the fact, but there is not currently a way of viewing this data in a digital and comprehensive format. In comparison, W.I.S.H. allows for real-time data analysis on the sidelines with an easy to use mobile application.

Figure 2.6.1-1: Reebok CHECKLIGHT system, in the skull cap (top), standing alone (left), and showing the USB Charger (bottom).

2.6.2 The X2 Biosystems xPatch:

Although X2 Biosystem's xPatch is not currently commercially available, it is scheduled to be released in Fall 2014. The xPatch is a much smaller and more compact device than the CHECKLIGHT. The device is small, allowing it to be applied anywhere comfortable on the player (seen in Figure 2.6.2-1) using an adhesive tape. According to the website, the system will be sold as a kit, including 12 or 40 units. The kit doubles as a charging station for all devices at once, making it easy to keep track of each device. In addition, the xPatch includes comprehensive software that is tablet compatible, allowing for field analysis of impact force, direction, impact history, and multiple user identification. This software communicates through a wireless connection with each device in the kit over a cloud computing system seen in Figure 2.6.2-2.

Though the price is not set yet, it is safe to say that the xPatch will not be a cheap product. The primary customer base of the xPatch seems to be major collegiate athletic programs as well as professional sports teams capable of paying for a more expensive product to keep their athletes safe.

Figure 2.6.2-1: X2 Safety System

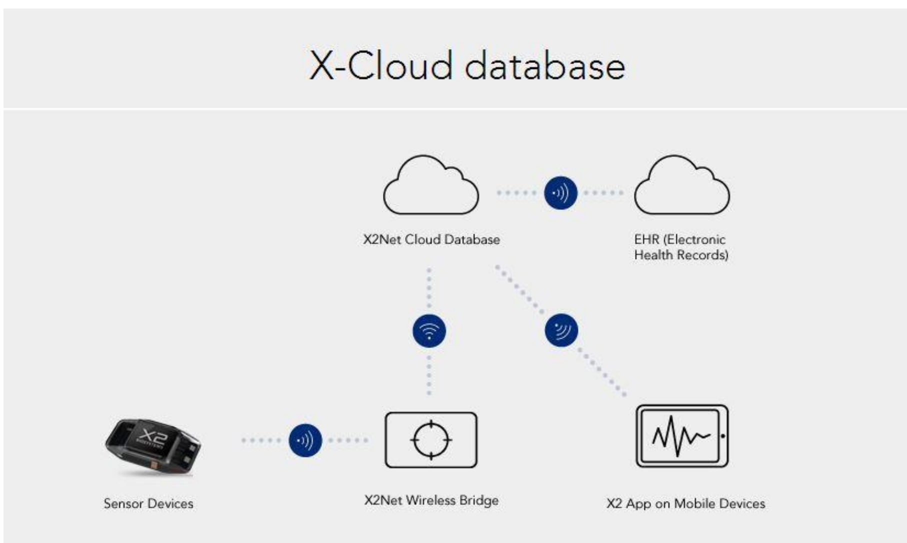

Figure 2.6.2-2: The system diagram shows the X2's use of cloud computing, the sensor and the tablet.

2.7 System Level Issues

As the W.I.S.H. system uses a headband instead of a skull cap, helmet embedded sensor, or others, some drawbacks need to be noted. Some of these drawbacks include potential variability in how the headband collects data depending how it's worn, long term durability, and constraints from its small size. There were concerns about the potential for varying data with a headband depending on how the athlete wears it. If worn in an insecure manner there is a possibility for the device to not adequately measure g forces. Another drawback is that due to intense comfort and size constraints, the long term durability of the device might be compromised. Since the device needs to be as thin and flexible as possible, this prevents the design from being enclosed in a robust housing, unlike sensors that are embedded into helmets. This also severely limits the size of the battery and therefore lessons its battery life. However, despite these tradeoffs our decision was swayed by the non-intrusive nature of a headband as opposed to the CHECKLIGHT, and the lower cost as well as the higher convenience than the X2 system. Therefore the W.I.S.H. system is a tradeoff between cost, performance, and convenience.

2.8 Team and Project Management

2.8.1 Project Challenges

The main challenge of this project was procuring a location to perform experiments. This took significantly longer than anticipated, and resulted in the team having less time to perform necessary testing. Group scheduling was also a significant issue that needed to be overcome in order for the team to work well together.

2.8.2 Budget

The project budget can be found in Appendix E. The total initial project budget was $800. The additional expected costs consist of testing equipment and materials that provided a greater fidelity to the simulation.

2.8.3 Timeline

A Gantt chart that illustrates the scheduled timeline of our project from January 1st onward can be found in Appendix F. Aside from a few interruptions, the timeline was largely adhered to for the duration of the project.

2.8.4 Design Process

This project started in a brainstorm based on the Nike+ Competition, where a donated accelerometer from Nike was required to be repurposed. The most realistic and useful device was determined to be a head trauma monitoring system. This idea was supported by the prevalence of high-profile athletes in the news due to repetitive head injuries. Research was conducted to identify similar products currently on the market. After review, it was determined that there was sufficient need for a low-cost product specifically for non-helmeted sports.

The next step was determining customer feedback through surveys and professional advice. This information was used to determine both product form and price point goals. Based on the results of a student survey, it was clear that the product needed to be cheap to buy, have aesthetically pleasing attributes, and cannot impede athletic performance.

2.8.5 Risk/Mitigation

Because this project was primarily concerned with the health and safety of others, there were many risks that needed to be evaluated and mitigated. One of these risks, arguably the one with the greatest potential danger for our team itself, was not physical in nature, but legal. The issue lies within the fact that the final head sensor system cannot diagnose a concussion. The complexity of a concussion and other similar traumatic brain injuries means that two identical impacts on the same subject can produce two different results, meaning in one instance the athlete is concussed, and in the other the athlete is healthy.

What this means is that our team needed to navigate a fine line; we cannot guarantee that this device will be able to diagnose when an athlete has a concussion. While we would love to be able to do so, there is not sufficient medical data on how to diagnose a concussion without using the standard physical and cognitive testing. By defining the project as a device that will alert the athlete of a potential risk, we can not only reduce the risk of an athlete continuing to play while concussed, but also the possibility of a lawsuit.

Additionally, the experimental testing done with our testing rig contained many inherent risks, as it repeatedly created high impact collisions. In order to reduce the potential risk of injury and ensure the safety of our team and others, necessary precautions were taken. These precautions include contacting the Santa Clara Environment, Health and Safety Director, Sean Collins, as well as the Risk Management team, along with using standard lab safety protocols and equipment. By doing so, the laboratory space required for testing was approved, and the general safety of the team was established. The major concerns about high-speed shrapnel in the event of a system failure were mitigated by operating the impact test rig in a low traffic area and using a safety shield constructed from medium-density fiberboard. A secondary concern regarding the noise created by the impact test rig was addressed by adding sufficient padding below the falling weights.

3. SUBSYSTEM DESCRIPTIONS

A description of the design, construction, and implementation of the individual subsystems of the Wireless Impact Sensing Headband, including the headband, impact test rig, and head and neck assembly.

3.1 Headband System

The headband system must be able to accurately and consistently measure impact accelerations and their directions across a range of 0 to 150 g. The headband and hardware system must be durable enough to withstand at least a year's worth of regular usage. In addition it must be waterproof to the extent that it should be able to withstand swimming and water sports. The ASTM IPX-8 standard specifies protection against water at depths below 1 meter. Also, to reach our target audience, the price of the final product must be low compared to the other competing products. Keeping this in mind, the goal was to create a headband that can be sold at no more than $100 retail value. A conceptual rendering of the headband and sensor system can be found below in Figure 3.1-1.

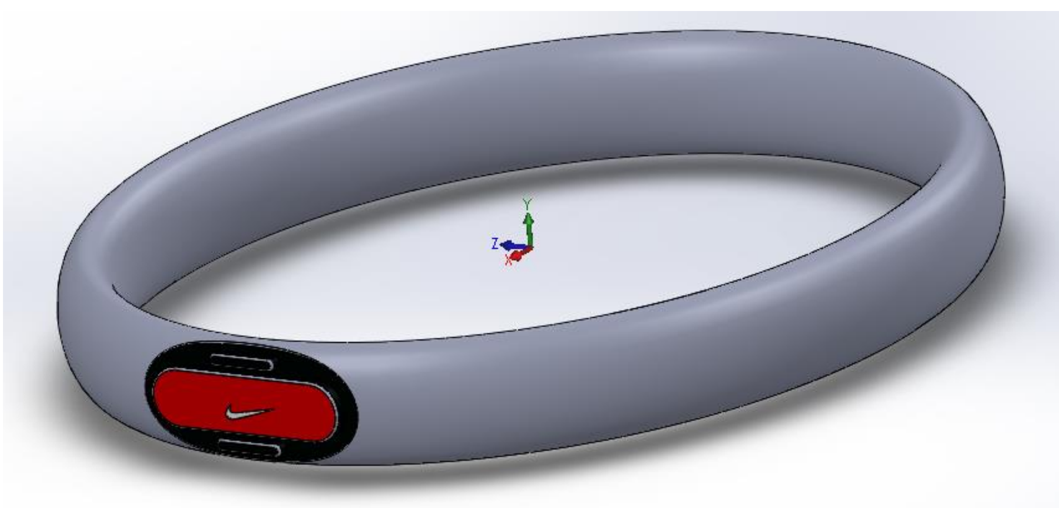

Figure 3.1-1: A conceptual 3D rendering of the headband and sensor.

3.1.1 Design Choice

The decision to incorporate the system into a headband instead of other garments was carefully analyzed. The majority of concussions occur among non-helmeted sports, making this our primary audience. With this in mind, several options were discussed including beanies, hair clips, hats, and skull caps. Due to a headband's unobstructed nature, acceptance among athletic styles, and wide use already (sweatbands and to keep hair back), it was found to produce the most desirable user experience.

3.1.2 Accuracy

The accuracy of the system largely depended on the quality of the accelerometers used. When looking at accelerometers, we required that they be accurate up to 150 g in force. Additionally, we looked for an accelerometer that could detect acceleration in the x, y, and z axis.

3.1.3 Durability

The system's durability largely depended on the parts and products that were chosen. It was important to maintain an appropriate durability while still staying within the price and aesthetic requirements as defined by the customer. This was a balancing act requiring the implementation of a large range of engineering knowledge to successfully execute.

3.1.4 Hardware

When considering the different components for the headband unit, several different categories were addressed specific to the component's use. Prior to this search, a set of specific criteria were determined in an effort to choose components that would allow for the successful operation of our product.

3.1.4.1 Wireless Module

One of the major components involved in the functionality and success of this product is the wireless module. As a result, we began our system research and design with the selection of a wireless module. Prior to beginning the search for a wireless module, a set of specific criteria were determined in order to choose a wireless module that would best fit our application. These included:

- A minimum outdoor range of 75 meters
    - A 75 meter radius guarantees that data can be reliably sent to the sidelines

from the athlete on any sporting field.

- Power consumption of less than 5 mW
    - Lower power consumption allows for the minimization of the battery, and therefore overall product.
- An on-board Analog-to-Digital Converter
    - Converting the signal from analog to digital on the device eliminates the need for additional hardware such as a second microcontroller, allowing for size minimization.

Upon determination of the selection criteria for a wireless module, we narrowed our search down to three major modules, all of which were widely available for testing and use. A comparison between the three candidates across the preselected criteria can be found below in Table 3-1.

Table 3-1: A comparison of wireless protocols

Product	**Bluetooth LE**	**Wi-Fi**	**XBee Series 1**
Range	10-33m	150m	100m
Power	0.147mW	210mW	1mW
Current Consumption	17.5mA	116mA	35mA
Wireless Protocol	Bluetooth SIG	Wi-Fi	Zigbee

From the table above, it is shown that the XBee Series 1 not only met, but exceeded all requirements for a wireless module to be used in the headband unit. As a result, we designed our system around the XBee Series 1, in terms of both power and size requirements.

The XBee Series 1 has a maximum outdoor range of 100 meters, allowing it to be used in virtually any standard sports arena. A low power consumption of 1 mW allows for selection of a smaller battery package, and thus aids in keeping the headband unit as small as possible. The XBee Series 1 also has a 2.8-3.4V supply range, which proved useful because the varying nature of a 3.3V battery's nature.

Figure 3.1.4.1-1: The XBee radio transmitter and receiver module.

3.1.4.2 Accelerometer

The next major component that was selected for use in the headband unit was a sensor that was able to accurately measure impacts commonly incurred in any major contact sport. The sensor chosen needed to be an accelerometer unit that came in a very small package size, to keep the overall unit as small as possible. Because most concussions occur from impacts ranging between 75-125 g, a high g-force threshold was the first major requirement when selecting an accelerometer. After researching different options, it became evident that the only commercially available accelerometer that could sense impacts within our targeted range was the ADXL377 from Analog Devices. This accelerometer is accurate up to 200 g, it comes in an incredibly small package (3mm x 3mm), consumes a very small amount of power (300 uA), and has a supply voltage between 1.8-3.6V, which is within the same range of the XBee Series 1. This allowed for use of a small battery package that could simultaneously power both the wireless module and the accelerometer.

Figure 3.1.4.2-1: The ADXL377 accelerometer integrated into a prototyping break-out board.

3.1.4.3 Microcontroller

The microcontroller was chosen based upon its processing power, support network, and ease of functionality with a computer-based user interface. Because the microcontroller was only going to be used on the receiving end, neither size nor power consumption were major issues. The main purpose of the microcontroller is to take in data from the XBee, convert that data to g force, and then display that force on the computer's serial monitor for the user to analyze. We decided to use the Arduino platform, rather than competing microcontrollers because of its incredibly simple user interface on any computer, along with its large online support network from other enthusiasts and programmers.

Originally, we chose the Arduino Uno. The Arduino was powered by the computer and then went on to power the receiving XBee with 3.3 V. The Digital Out pin from the XBee went to the Receive pin on the Arduino. With this setup, however, we were getting data corruption. Because of this, we upgraded our microcontroller to the Arduino Mega 2560. An image of the Arduino Mega 2560 can be found below in Figure 3.1.4.3-1. The setup was essentially the same, except that the Arduino Mega 2560 has Hardware Serial pins for the Rx pin, while the Arduino Uno only has Software Serial pins. The Hardware Serial pins allowed us to increase the sample rate, process the data, and display it in real time.

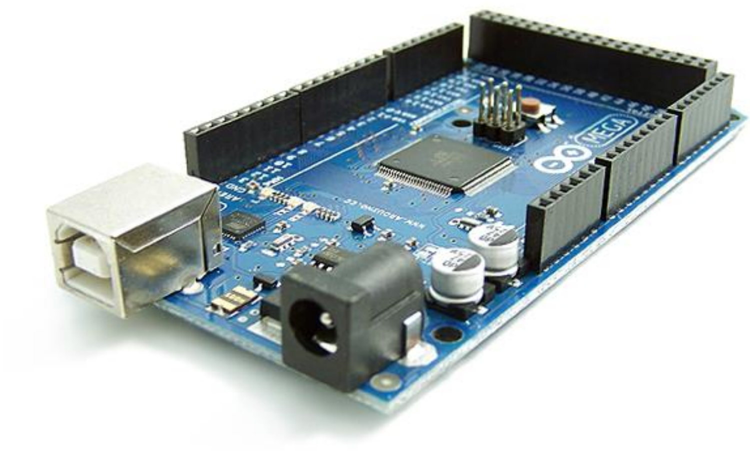

Figure 3.1.4.3-1: The selected microcontroller, the Arduino Mega 2560

3.1.4.4 Power Supply

Upon selection of both a wireless module and a sensor, the next step was to select a power supply that would be able to power the entire headband unit, while still keeping the unit as ergonomic as possible. Desired specifications included:

- High battery capacity
  - Needs to power the system for the an entire game (2.5 hours)
- Small package size
  - Small enough to fit in the headband so it does not impede athlete's abilities
- Rechargeable
  - Eliminates wasteful battery consumption and cuts down on cost for user
- Nominal voltage between 2.7-4.2V
  - Needs to power both the XBee and the accelerometer

With these specifications in mind, we decided to go with a Lithium Ion Polymer, or Li-

Po, battery. The specific Li-Po battery we picked has a capacity of 110 mAh. Our transmitter system as a whole draws about 50 mA. This means that the battery would be able to power our system for over 2 hours, enough for any sporting event. It has a nominal voltage output of 3.3 V and ranges anywhere from 2.7-4.2 V. It is small (28mm x 12mm) and lightweight (<4 grams). Additionally, this battery has been industry tested to have no effect on output voltage during collisions or drops, making it perfect for our application. An image of the selected battery can be found below in Figure 3.1.4.4-1.

Figure 3.1.4.4-1: The lithium ion polymer battery selected for use, with a quarter for size comparison.

3.1.4.5 Power Management

Due to the varying nature of the Li-Po battery's voltage, it was imperative that a power management system be implemented into the headband unit. This would guarantee a constant 3.3V supply to the rest of the system, regardless of the battery's output. Desired specifications for a power management system included:

- The ability to both step-up and step-down input voltage
    - Guarantees a constant 3.3 V supply regardless of battery's voltage
- A high efficiency (>90%)
    - Allow for selection of smaller battery package that would last for the duration of any standard sporting event
- Availability of a small package size with minimal additional circuitry
    - Aid in the effort of keeping the headband unit small and ergonomic

The search for a power management system began by looking at systems that would only step-down the voltage to 3.3V. This was done for testing purposes with larger, more available batteries like AA, AAA, and 9V, along with the misunderstanding of the varying nature of a battery's voltage as dependent on charge. Once this varying nature was realized, the search for a power management system was narrowed down to chips that could both step-up and step-down an input voltage to guarantee a constant 3.3V supply. The search ended with the selection of the LTC3440 LT by Linear Technology. This IC not only met, but also exceeded all desired specifications for a power management system. A comparison between the different candidates for the power management system can be found below in Table 3.1.4.5-1.

Table 3.1.4.5-1: A comparison of different power management integrated circuits

IC	Input Voltage	Output Voltage	Quiescent Current	Efficiency
RT9193 *RichTek*	2.5 - 5.5V	1.5 - 4.5V	90uA	92%
LP2950 *TI*	2.1 - 16V	2.5 - 5V	65uA	90%
NCP5030 *ON*	2.7 - 5.5V	2.2 - 5.5V	5000uA	87%
LTC3440 *LT*	2.5 - 5.5V	2.5 - 5.5V	600uA	94%

3.2 Design Process

3.2.1 System Block Diagram

The beginning of our design process involved conceptualizing a more general system-level block diagram. This involved realizing the systems and components necessary for both the transmitter and receiver units, and how they would be powered and interconnected.

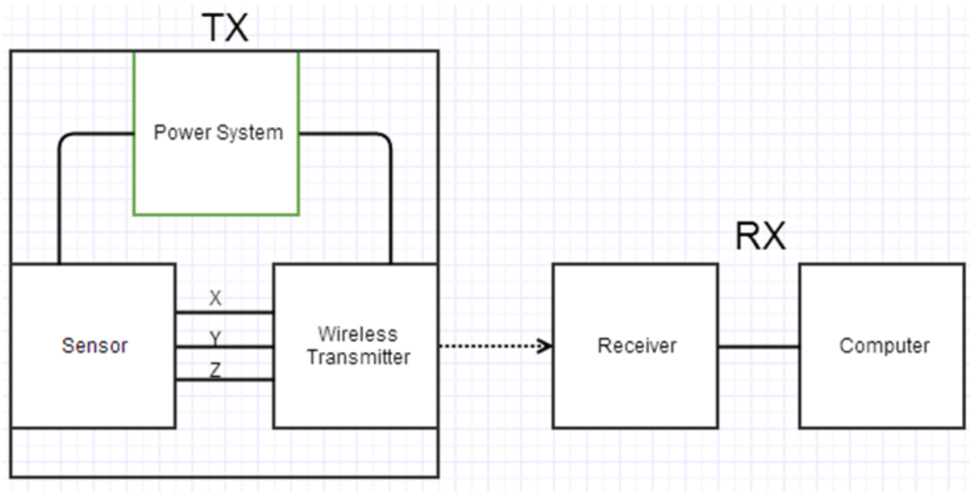

Figure 3.2.1-1: Block diagram displaying basic transmit (TX) and receive (RX) modules of W.I.S.H.

After conceptualizing the overall layout of our system, we went through the search process outlined in the previous section and selected all components necessary for a functional system.

When designing our system, we initially began by testing all of our products individually to ensure all of our hardware was compatible with each other. Our first test was to exclude the wireless aspect and just ensure that the ADXL377 was able to function with our Arduino. We were able to read output voltages on the Arduino Serial monitor using this setup. The next step was to convert these output voltages to g force measurements. We did this by looking at the sensitivity of the accelerometer. From the data sheet, we found the sensitivity to be 6.5 mV/g. This value allowed us to convert the output voltage to g force.

3.2.2 Breadboarding

The next step was to add in the XBee and make our system wireless. We first went about this by breadboarding our system. Our transmitting system can be seen below in Figure 3.2.2-1. This stem consists of the ADXL377, the remote XBee, and a power source. Our receiving stem can be seen in Figure 3.2.2-2. This system consists of the coordinator XBee and the Arduino Mega 2560. From this setup, we were able to transmit accelerometer data wirelessly and display it on the computer's serial monitor. This allowed us to ensure that our system was functional and move onto the next phase.

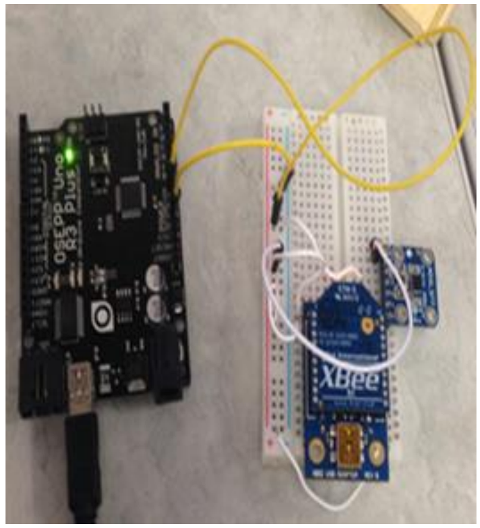

Figure 3.2.2-1: The breadboarded transmitter system, including the ADXL377 (far right) and the Xbee (center).

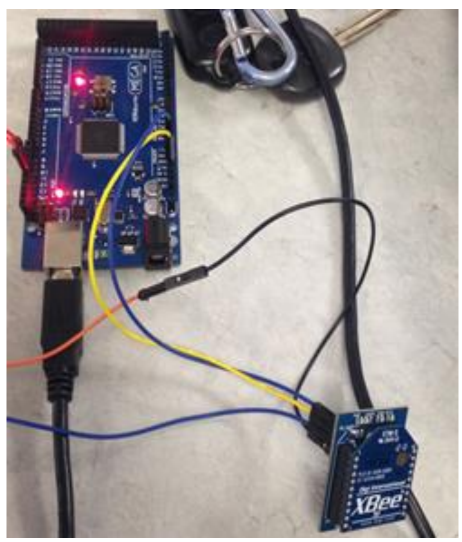

Figure 3.2.2-2: The receiver system, including the Xbee (bottom right) and Arduino Mega 2560 (top left)

3.2.3 Printed Circuit Boards

The next step of our project was to turn our transmitter system into a printed circuit board. For our first revision, we made two separate boards, a power board and a system board. Our power board takes in a voltage and outputs a constant 3.3 V. This board can be seen in Figure 3.2.3-1. The output of the board goes to the input of our system board.

Our system board houses our accelerometer, our remote XBee, as well as some passive components. This board can be seen in Figure 3.2.3-2. After testing both of these boards, we went about implementing both of these boards into one final board. This transmitting board can be seen in Figure 3.2.3-3. The main focus when designing this board was to make it as small as possible.

Figure 3.2.3-1: Power Board

Figure 3.2.3-2: System Board

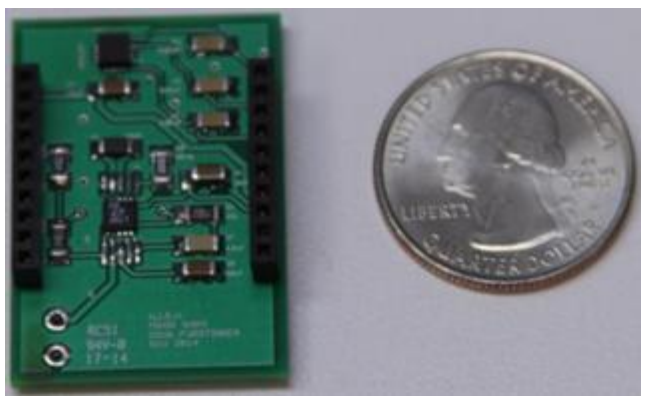

Figure 3.2.3-3: Transmitter Board

3.2.4 Complete System

Finally, having turned our transmitter system into a printed circuit board, we were able to implement it into our complete design. Our complete design consists of our receiving module and our transmitting module. This can be seen in Figure 3.2.4-1. We were able to validate that the system as a whole works and wirelessly sends data from the accelerometer to our receiving module, where it is converted to g force and then displayed on the computer's serial monitor in real time. Our system as a whole transmits data 40 times per second, or once every 25 milliseconds. This transmit speed allows us to capture instantaneous impacts as they happen so no collisions are missed.

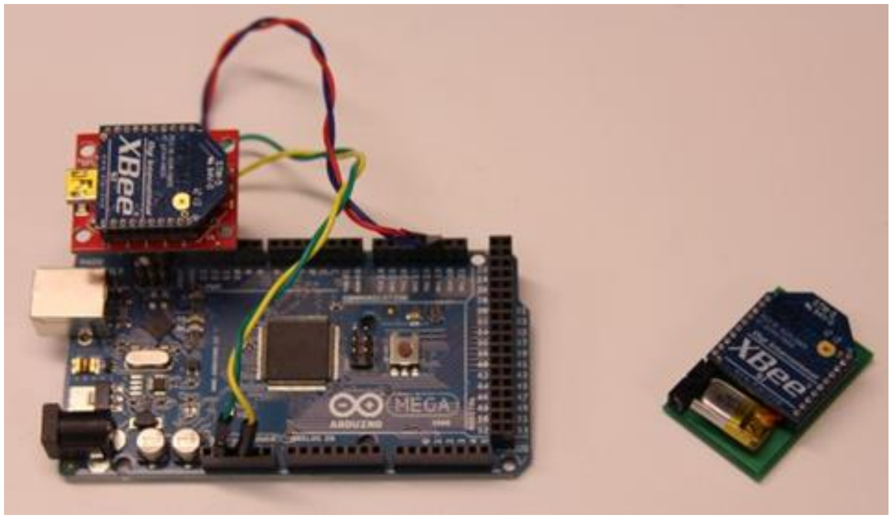

Figure 3.2.4-1: Complete System Consisting of Receiver and Transmitter

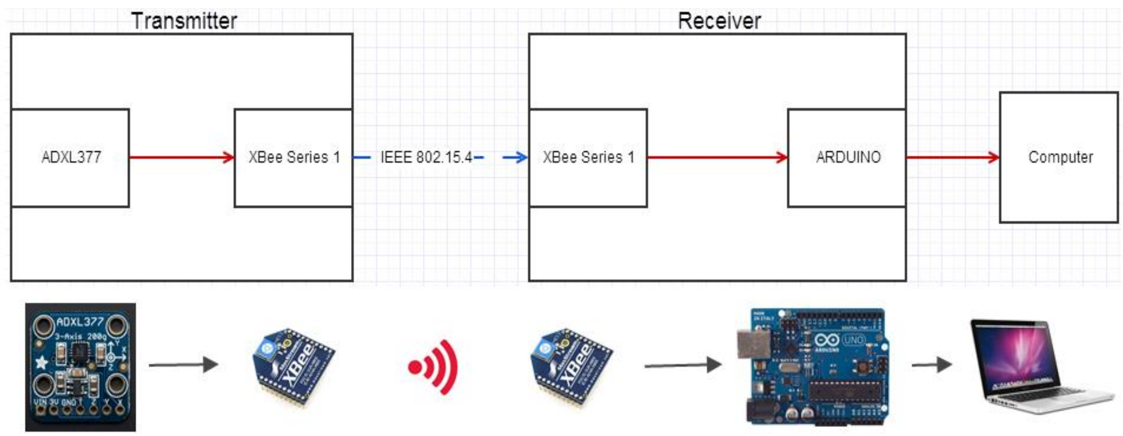

Figure 3.2.4-2: Complete System Block Diagram - Data Stream

3.2.5 Range

We then tested the range of the system. Because this product is modular and can be used for many different sports, we tested both indoor and outdoor range. When testing indoor range, we found that the system can transmit wirelessly over 60 meters. Outdoors, our system was able to transmit at a range of 100 meters. Both of these values are more than enough for any sport.

3.3 Testing Rig

The importance of adequate testing is paramount due to the nature of the product being a medical device. After all, someone will be counting on the headband's accuracy and reliability. Therefore a testing system is required that can deliver accurate and repeatable forces in many different configurations. To do this, a second sensing system was used to provide comparative truth data, or control data, to the data supplied by the wireless headband. This allowed us to verify that the wireless system was accurate and adjust the calibration as needed.

There are a variety of machines used for head impact testing that use different methods to achieve high acceleration impacts. These include pendulum impactors, linear impactors (electric and pneumatic), and drop towers, all of which are shown in Figure 3.3-1 and Figure 3.3-2. Pendulum impactors are simple devices that use gravity to swing a mass at a target object. Linear impactors, as their namesake implies, apply a force in a linear manner and use either an electric actuator (such as a powerful solenoid), or a powered fluid like compressed air. Finally, a drop tower is a gravity powered mass free-fall device that typically impacts a target at the end of a vertical track.

Figure 3.3-1: Commercial examples of test rigs. L**eft:** Pendulum Impactor. **Right:** Electromagnetic Linear Impactor

Figure 3.3-2: Commercial examples of test rigs. **Left:** Pneumatic Linear Impactor (air cannon). **Right:** Drop Tower

We analyzed each system from a standpoint of our own capabilities. The factors that were of the greatest concern to us were cost, physical size (footprint), design complexity, and safety. The results were then qualitatively tabulated in Table 3.3-1.

Table 3.3-1: Qualitative testing rig comparison chart

Test Rig System	Cost	Footprint (ft^2)	Design Complexity	Safety
Pendulum	Low ($300)	24-30	Low	Medium
Linear Impactor (Air Cannon)	Medium ($1000+)	50-75	Medium	Low
Linear Impactor (Electrical)	High ($2000+)	50-60	High	Low
Drop Tower	Very Low ($200)	24	Very Low	High

Unfortunately all of the commercial options were far outside of the team’s budget. As our budget was severely constrained (~$300 for the test rig), we instead opted to construct our own system In the end we chose to use a drop tower system due to its extreme simplicity, relatively benign nature, low cost, and compact shape. This decision was also heavily influenced by our realization that instead building a rig from scratch, we could instead convert home gym for our needs. This decision saved us time, money, and was a great platform to expand off of. From there we purchased a used home gym, which is shown in Figure 3.3-3.

Figure 3.3-3: Exercise machine that was converted to custom drop tower

Once all of the unnecessary components were removed we designed a way for the system to work as a test rig. A rough calculation using Newtonian potential and kinetic energies was also done to verify that the height of the rig was enough to produce the required impact. We found that 150g could easily be produced with 40 lbs. dropped from 2.5 feet.

We then modified the system with a quick release mechanism (Figure 3.3-4), a mounting bracket system, and a protective shock absorption system. The quick release mechanism incorporated a quick release shackle for use in marine vessels as well as various threaded adapters so as to use as much of the existing mechanics of the weight machine as possible.

Figure 3.3-4: Quick release mechanism as installed

To allow the test rig to accept a dummy head a mounting rig was necessary. Initial ideas involved bending sheet metal “sandwiches” that would encase the weights and allow us to mount other components to it through various adapters etc. This idea was eventually abandoned in favor of a much simpler and more adaptable threaded rod and steel bar system. Both of these can be seen in Figure 3.3-5. Once implemented, the attachment system effectively contained the weights of the test rig into a single mass, providing more consistent results.

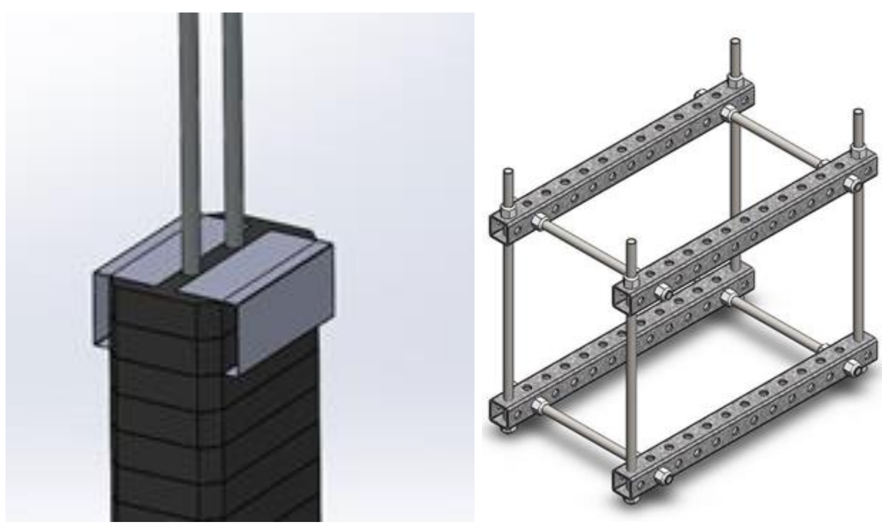

Figure 3.3-5: Progression of mounting/attachment systems **Left:** Bent sheet metal system **Right:** Threaded rod and steel bar mounting bracket

Finally, one of the most important additions for the long term use of the test machine was a shock absorption system. Without such protective measures the machine would likely suffer from extreme fatigue and stress fractures from forces imparted to the frame from each drop. Thankfully, this turned out to be a simple implementation as we were able to recycle foam sections from the weight machine and place them underneath the weights. This was purposely timed to only slow the falling head/mass after the dummy head had already impacted its target, thus minimizing variations.

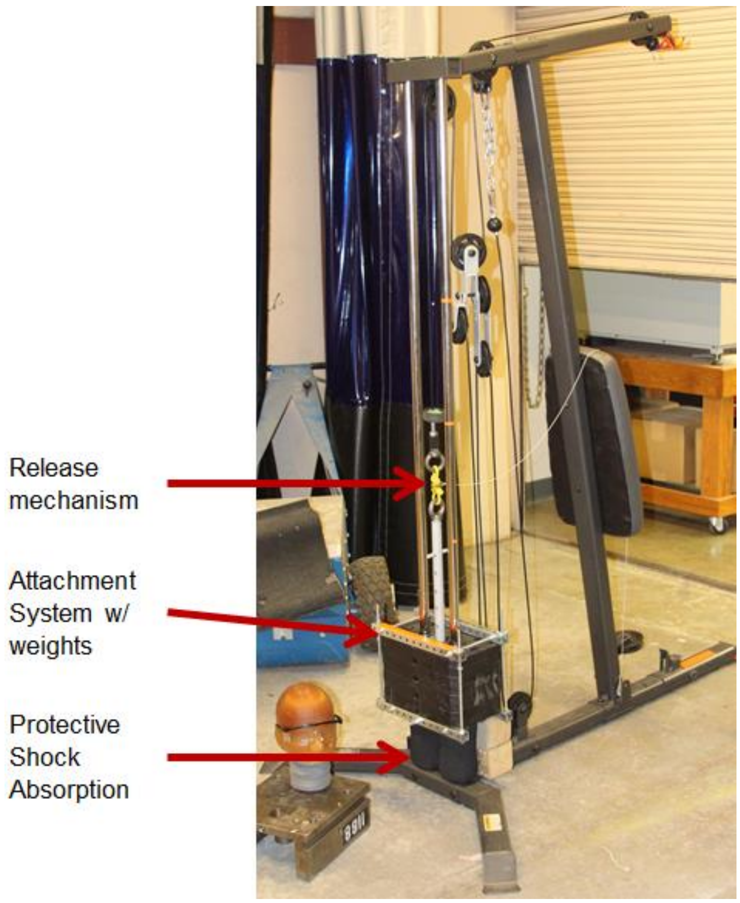

Figure 3.3-6: Completed Test Rig

3.4 Crash Test Dummy

A test dummy head and neck assembly was on the receiving end of the impact forces to simulate the effects on a real head and neck, as shown in Figure 3.4-1. The dummy head and neck was outfitted with commercially calibrated accelerometers which served as our truth data to compare against the results recorded by the headband sensor system. Unfortunately the substantial cost of buying, or renting, a dummy head such as the Hybrid III crash test system, prevented us from using an existing head. Therefore, a custom dummy head and neck was made that approximates, as closely as possible, the performance of a standard 50th percentile male dummy head and neck. Our own custom head was projected to cost roughly 5-10% that of a commercial head, or about $200-400. The final head cost only $160.

Figure 3.4-1: Hybrid III commercial crash test dummy head and neck assembly.

3.4.1 Dummy Development

The custom crash test dummy head and neck was developed to mimic the Hybrid III, 50th percentile, male crash test dummy. With this goal in mind, materials were chosen based on price as well as ease of use. Table 3.4.1-1 shows a comparison of the Hybrid III and our custom dummy assembly.

Table 3.4.1-1: Comparison of Hybrid III crash test dummy and custom crash test dummy.

	Bob (Custom Dummy)	Hybrid III 50th% Male Dummy
Weight [lbs]	8	13.4
Height [in]	12	12.4
Core	Epoxy	Aluminum
Skin	Polyurethane	Butyl Rubber
Neck	EVA foam w/ steel spacers	Butyl Rubber w/ steel spacers
Cost [$]	150	6000

The weight difference between the two systems is largely due to the Hybrid III's sensor package, which is embedded in the core of the head. An epoxy core was chosen because of its weight, and its ease of use. In addition, using fast cure epoxy made it easy to embed a carriage bolt in the core allowing for easy attachment and detachment from the assembly. A slow curing polyurethane skin was chosen as a skin material because it allowed the team to embed the epoxy core in the head and use gelatin as a cheap mold material. This significantly reduced the overall price of the head while maintaining similar performance.

The neck was made of EVA foam disks which were cut from foam flooring pads. These disks were then spaced out with steel disks to give the neck more strength and rigidity. Finally, a steel cable was run through the neck and secured on both ends to adjust the tension of the neck. This gave the team the ability to adjust the neck tension to better match the Hybrid III dummy. The final custom head and neck system cost the team under $200 and can be seen in Figure 3.4.1-1.

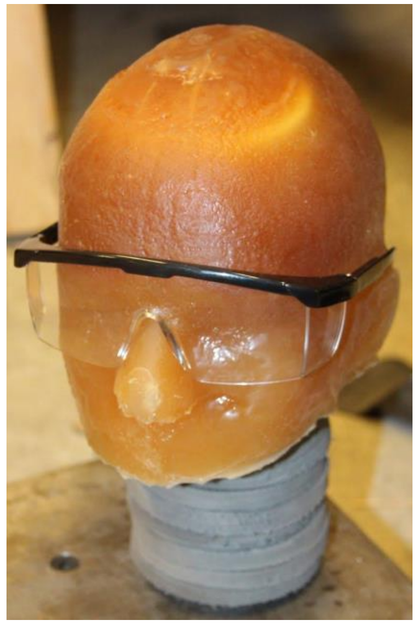

Figure 3.4.1-1: Final head and neck assembly

3.5 Product Housing

Our Product housing was designed in an iterative process using standard ABS plastic in a 3D printer. The first iteration was created specifically as a testing vehicle. This needed to contain the electronics in a stable manner, but also needed to survive hundreds of impacts. This first iteration can be seen in Figure 3.5-1 and Figure 3.5-2.

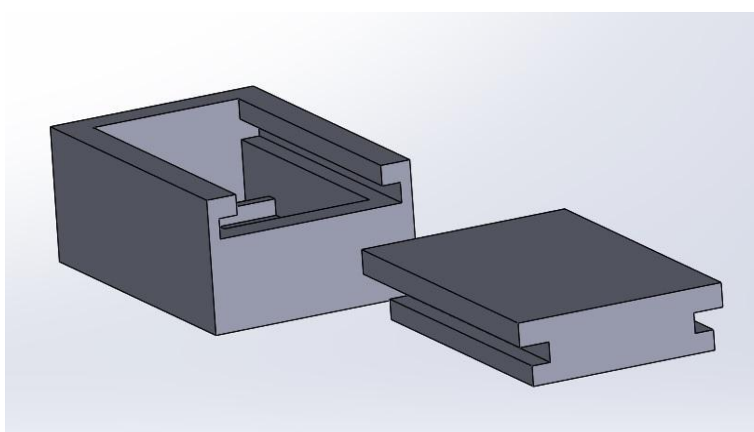

Figure 3.5-1: SolidWorks rendering of housing iteration 1.

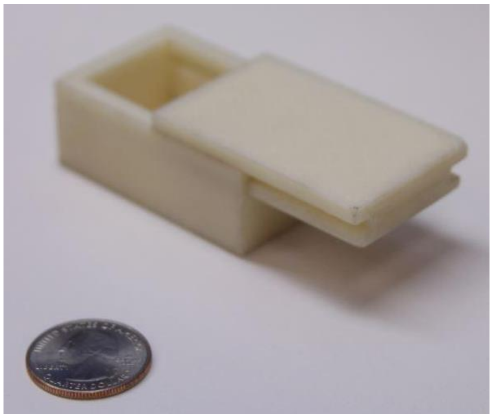

Figure 3.5-2: Housing iteration 1 with quarter for scale.

The second iteration was created with the consumer in mind. The volume and weight was reduced by about a third compared to the first iteration. The aesthetics of the housing were also improved. The team experimented with the color as well as shape of the container. This iteration can be seen in Figures 3.5-3 and 3.5-4.

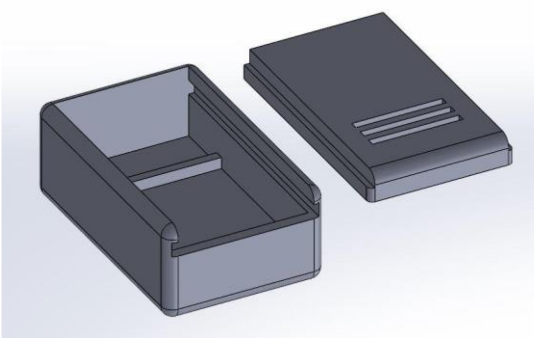

Figure 3.5-3: SolidWorks rendering of Housing iteration 2.

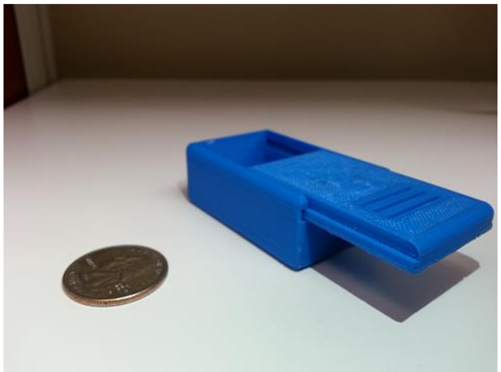

Figure 3.5-4: Housing iteration 2 with quarter for scale.

4. SYSTEM INTEGRATION, TESTING

The accuracy and validity of the data produced by the sensor system was tested using a custom designed rig capable of simulating a range of impact forces. The testing rig, which was a blunt striking surface, impacted a head and neck model. The head and neck assembly was outfitted with a calibrated and certified accelerometer (ADXL377), which served as "truth data" to compare against the results recorded by the sensor system.

The head and neck assembly was oriented so that the striking surface was parallel with the plane of the forehead. The first task was to verify the consistency of the drop tower and dummy head. This was done by dropping the head on its forehead with only the wired sensor on bored which was positioned at the back of the head (z-axis facing up). This orientation of the head and neck was then exposed to a total of 20 impacts from a two foot drop height.

After the rig was tested, a similar process was conducted to validate the headband wireless transmitter itself. The head and neck assembly was exposed to a range of impacts with the striking surface impacting the forehead as before. The wireless sensor and wired sensor were placed next to each other at the back of the head so as to have as similar a measurement as possible. There were 15 tests done with this setup, 5 at a 1 foot drop, and 10 at 2 feet. The data recorded in all trials was compiled and analyzed by both LabVIEW and Microsoft Excel for the wired and wireless systems accordingly.

4.1 Test results

After the 20 separate drops for the rig validation were done from two feet we measured an average of approximately 200 g produced by the system. This was about 50 g higher than we had hoped for from our rough calculations. The rig performed with an average accuracy of +/- 2.5 g and with a maximum difference of 6.5 g which is a greater accuracy than anticipated. In addition, the testing rig system showed no significant decay in results over time with a standard deviation of only 3.685 in the maximum g force. This means that both the testing rig and dummy overall performed better than anticipated. The data collected can be seen in Figure 4.1-1.

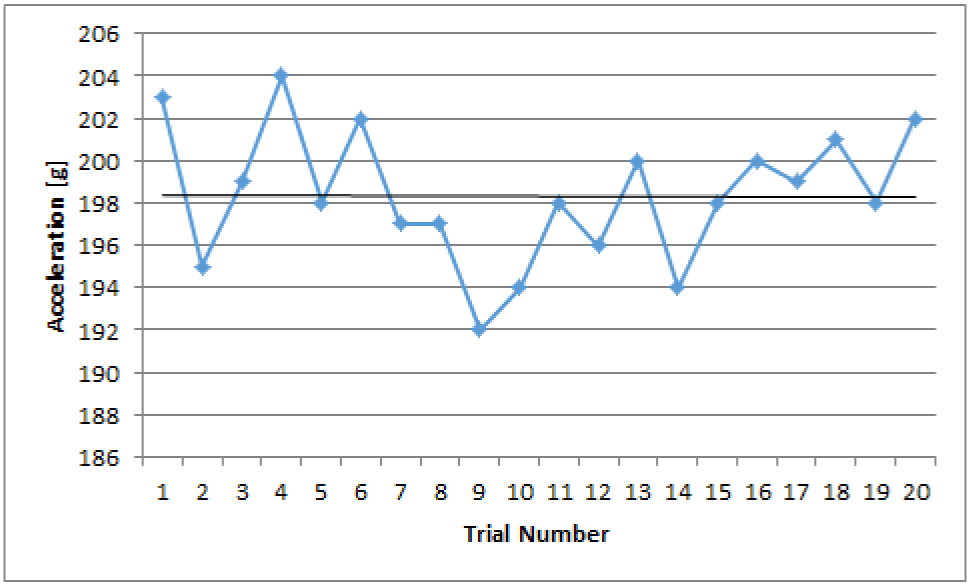

Figure 4.1-1: Test rig validation trials from truth data sensor

Finally, to ensure that the headband system would work correctly, additional wired truth data was collected simultaneously with the wireless impact data. Since the sensors were in very close proximity to each other the team expected them to measure very similar results. Overall, the team was not able to perform as many tests as desired, but 15 were successfully performed with the headband in place. Ten of these tests were done in conjunction with the truth data validation at a 2 foot drop. Unfortunately, during testing, it was noticed that the sample rate of the W.I.S.H. receiver was too low/slow to reliably measure the extremely fast impacts. The impacts typically occurred within 5ms but the sample rate of the receiver was only 25ms thereby missing several impacts. This was a forced limitation by the receiver's microcontroller and will be easily fixed in future revisions. This flaw can be seen by comparing Figure 4.1-2 and Figure 4.1-3. It was observed that this flaw is especially exaggerated at impacts above 200g.

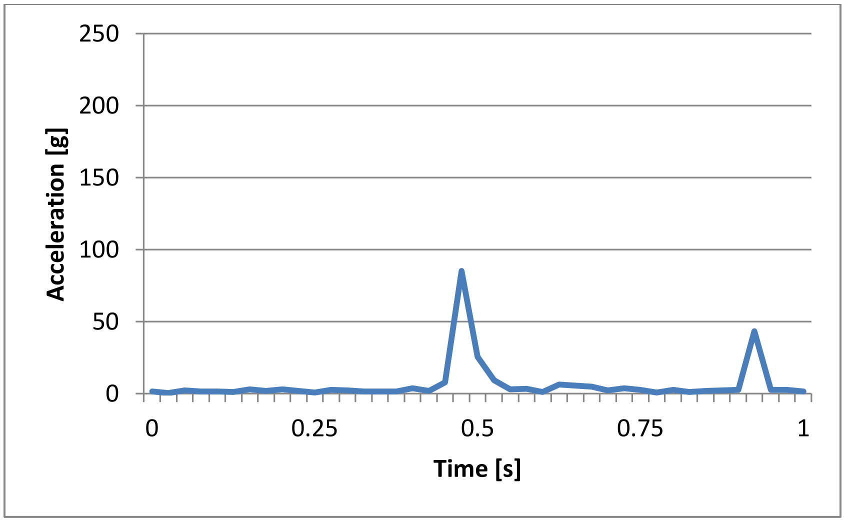

Figure 4.1-2: Example of failed wireless data collection

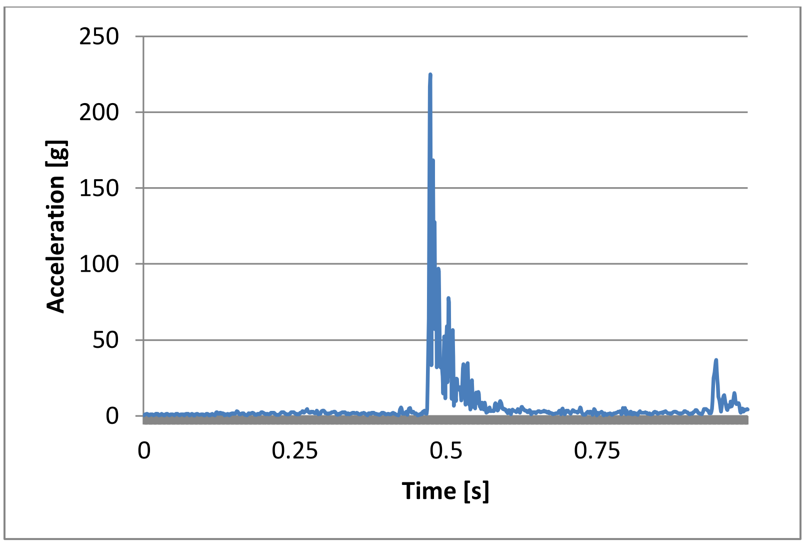

Figure 4.1-3: Wired control data of failed wireless data collection

However, if the impact is successfully collected, there is no significant difference between the collected wireless and wired impact data. After observing the difficulty of successfully collecting the data at 2 feet, the height was dropped to a 1 foot drop. Successfully collected data from one of these drops can be seen in Figure 4.1-4 and Figure 4.1-5.

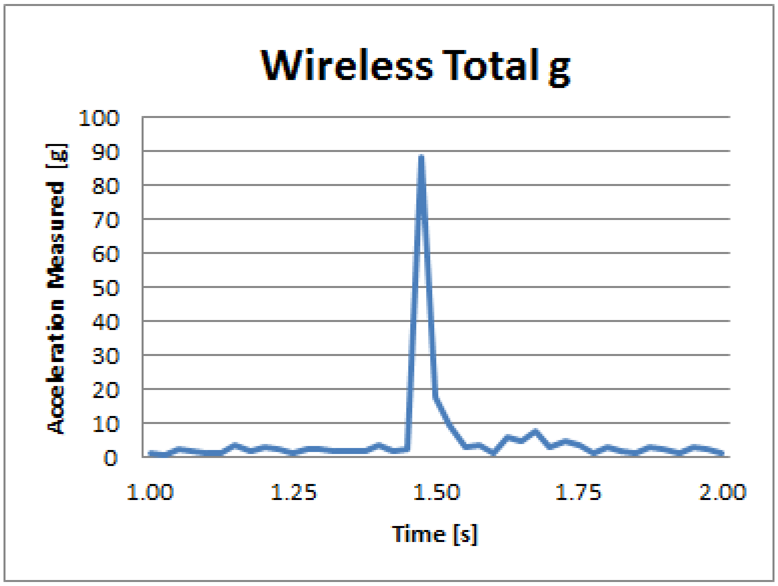

Figure 4.1-4: Example of wireless module data collection set.

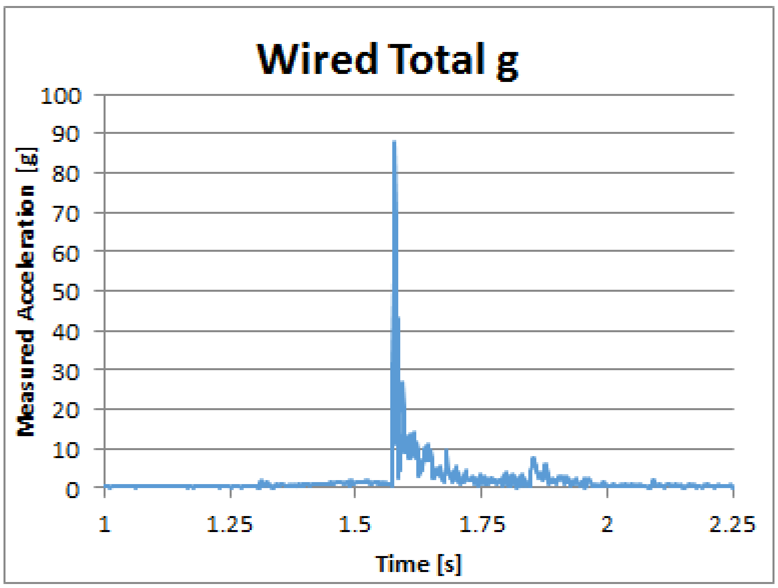

Figure 4.1-5: Example of wired data collection set.

5. ENGINEERING STANDARDS AND REALISTIC CONSTRAINTS

5.1 Manufacturability

In order to reach our target market of the broader amateur athletic community, the cost of the end product needs to be very low. Due to this cost restriction, manufacturability and the cost to manufacture our product are two major criteria to the success of this product in the mass market. Our product was designed primarily for prototyping where cost on low quantities is important. However, this cannot be cheaply manufactured on a scale of 5000 or more units without modification. The limitations of 3D printed parts include a low rate of production, poor cost scalability, and non-ideal surface finishes. This then promotes the need to find a better method for high quantities, which may include injection molding.

Injection molding is ideal because it allows the housing to be produced quickly and with much lower material costs. When injection molding is compared with high volume production of 3D printing the cost of the parts can be reduced to a fraction of their current values. Our current 3D printed design can be produced for a little under $21 a unit. By comparison if the same housing were injection molded, its cost drops to around $5 a unit. With an improved design, the cost could be reduced much further. To accomplish this, certain guidelines need to be followed to optimize part costs. Like the prototype, the housing will be constructed of a low cost plastic such as ABS. However, since the injection molding process is very different, part thicknesses, liquid plastic flow channels, and draft angles all need to be considered for part design.

Additionally, the size of our product design needs to be reduced by at least 50% or more. The current design was developed as a means of testing our unit in a compact and secure manner. An updated design requires a much smaller and sleeker structure to provide the wearer with a comfortable system. Without such comfort taken into account, our system runs the risk of not being worn, a major concern. Future design changes also must include complete waterproofing, where sweat and rain are also concerns as well as use in aquatic sports.

5.2 Sustainability

Our project aims to be as sustainable as possible. The device is useful for a long period of time and for many people. It is not a toy nor designed to be a fad. This device has real impact on the world of sports, and the technology is sound stable enough to not warrant replacement in the future. Therefore, our product aims to last through regular use.

Additionally the aspect of a rechargeable battery allows the product to be much more economical as well as saves waste. Our original plan was to make a device that had a non-rechargeable lifetime battery so as to increase sales. However, this was deemed unsustainable because of its size as well as price preventing the technology from reaching as broad a market as possible. The downside of using a rechargeable battery is the reduction in recyclability; rechargeable batteries are simply more difficult to break down.

This leads to the problem of producing for a mass market; the creation of such a large number of products, no matter how useful and long lasting, will invariably lead to more waste. This increase in waste will have a negative impact on the sustainable nature of our product and must be minimized. While the mechanical housings and battery can be recycled the electronics themselves present the biggest problem. Electronics are notoriously difficult to disassemble, and generally only small amounts of gold and other high value materials can be extracted. Unfortunately there is very little that can be done with regard to electronic recycling. However, by minimizing the number of dyes and other toxic production processes within the housing and by using battery technology that is long lasting, these effects can be minimized.

5.3 Health and Safety

The entire purpose of this product is to increase the health and well-being of the wearer. Nearly 6 in every 1000 athletes experience a concussion each year (Cassidy). As many as 20% of these athletes will experience a second concussion (Cantu). It is our goal as a team to prevent this second concussion from further damaging the player’s health. This is done using a real time alert system on the receiving end of the sensor. If a player incurs a force that could potentially have resulted in a concussion, the trainer, parent, or coach on the sideline would be notified immediately that the player needs to seek medical attention. Our system gives the observer a not only notification, but a number determining how hard the player was hit. This helps keep coaches and trainers honest. Rather than being able to risk a player's health for a championship game, the number would be recorded, giving hard evidence for the player's injury rather than a simple sideline estimate.

5.4 Economic Issues

One of the primary goals that need to be achieved for our product to be deemed successful is its economic viability, for both the producer (us) and more importantly the consumer. On the production side, we have estimated that we can purchase all of our electronic components and housing for just over $30. The quantity of components required for this cost, 5000 units, reflects the scalable prices from the electronics manufacturers; in other words we will save a large amount of money by purchasing them in bulk. In comparison, our prototype, which used individually purchased components, cost us $150. A loan of $150,000 would be enough to cover the component costs, the majority of the costs required by the project (assembly/construction is very simple). A hypothetical price of $45 per unit would recover the loaned money after selling 3333 units. Of course there are many more nuances and complexities required in a business model, but this quick calculation demonstrates that the loaned money could be recovered by selling just over 3000 units, which is not very many in comparison to the number of potential consumers.

However, our more important goal is to ensure that this product remains economically viable for the consumer. There are similar products available on the market today, but they are relatively expensive, upwards of $250. The price of the competing products prevents a large majority of athletes from being able to even purchase it, let alone use it; the price excludes most people who are not professional athletes, which includes students (and their parents), as well as older amateur athletes. The hypothetical $45 price would allow the previously excluded population to also use this product at a reasonable price for their health.

5.5 Social Issues

This product is rooted in, and relies upon the athletic community for its success. As a product, its purpose is explicitly to help athletes detect dangerous head injuries. If, for any reason, an athlete does not want to wear the device, it is essentially useless. Assuming that the product can be developed so that it is comfortable and does not impede athletic ability, it is still important to address another subjective component, style. The sensor system could function perfectly, but if the athletes simply do not like what they look like wearing it, a large majority will choose style over their health.

These problems have already been found in sports such as hockey. In 1979, the NHL began to require the use of helmets, which were previously optional. Many players had rejected the ruling, requiring the inclusion of a grandfather clause which allowed all players who had signed their professional contract before 1979 to not wear a helmet. The players rejected helmets for a variety of reasons, including comfort and style, or lack thereof (The Vancouver Sun).

This product could also have impacts which are harder to fully foresee, such as the impact on the sport itself. Sports teams are already beginning to record and analyze a wealth of data including impact acceleration, field positioning, and heart rate, to use predictive analytics, to prevent injuries and increase the success of the team. This data is used to understand where the players are most vulnerable, and which strategies do and do not work. Teams will also aggregate quantitative data about past injuries. This data could increase the longevity of the athlete’s career, and even life (IBM).

6. SUMMARY AND CONCLUSION

6.1 Summary

Through the design of a functional validation system for our product, we were able to prove the accuracy of our wireless impact sensing headband unit. The device is able to accurately detect, transmit, and process most impact data throughout the range of impact magnitudes commonly found to cause concussions. A step-by-step approach to hardware design and testing, along with a detailed trade-off analysis between many different options for component selection, all played a major role in allowing us to achieve such a high level of accuracy and functionality from our system.

6.2 Future Work

While the device is accurate and functional, this prototype model is not yet ready for the mass market. Immediate changes that will help bring this product to the mass market include several changes in component selection, increase of ergonomic nature, and enhancement of the product casing.

In order to accurately sense and measure impacts in real-time, it is necessary for us to have a sampling rate on both the transmit and receive ends that allows us to capture and analyze impacts at their peak - an event that often lasts for a fraction of a second. As a result, we will have to use a microcontroller that is able to receive all of the incoming signals - closer to 1000 samples per second - and process the data quick enough to be relayed onto the screen in real time.

In addition to severely increasing the sampling rate of the system, component reselection and modifications must be made to create a more ergonomic and cost-effective product. Due to its prototype nature, the transmitter end is currently too large to be added safely and effectively to a headband. Because the wireless transmission module is currently the largest component in the transmitter unit, the integration of a custom transmitting radio will allow for a smaller, more ergonomic packaging.

Recharging circuitry for the battery is another immediate addition necessary for the functionality of this device through many instances of gameplay. Adding charging circuitry to the transmitter unit would not make the transmitter unit much bigger in size, and is therefore an immediate and imperative next step in the enhancement of the system. With more research and time, housing the device in a waterproof case will allow for a player to use the headband in the rain, and even in aquatic sports. Waterproofing would not only allow the product to be more durable, but also expand our target athletic audience to include sports such as water polo and wakeboarding.

In addition to immediate physical changes, there are several long-term additions that would make this product even more robust and informative. To start, a more intuitive user interface would significantly improve the existing product design. Making the system compatible with smartphones and tablet interfaces would allow for easy sideline use by parents, trainers, and coaches, and would make the data much easier to share with others for even more analysis and interpretation. This will potentially lead to more immediate diagnosis of a traumatic brain injury.

The market reach of this product extends far beyond impact sensing on the playing field. In the future, this product is applicable and useful to the entire athletic community. With an incredibly small design that can be implemented into any sort of headgear, this product has the capability to be in any standard headband or helmet, and not be cumbersome, obtrusive, or dangerous to the user. The product also has the potential to be a key player in future predictive analytics, allowing players and coaches to not only detect and prevent injuries with more accuracy and frequency, but also measure, analyze, and predict progress towards user’s specific goals regarding athletic performance and gameplay strategy.

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Appendix A: Product Cost Analysis

Mass Production Model (5000 units):

Component	Unit Cost
XBee Series 1	$20.00
ADXL377	$5.75
LTC3440	$2.75
Microcontroller (MSP430 - TI)	$0.45
Additional Passive Circuitry	$1.05
PCB Fabrication	$2
Housing	$0.50
Total Cost	$30.50

Prototype Model:

Component	Unit Cost
XBee Series 1	$35.00
ADXL377	$9.15
LTC3440	$5.85
Microcontroller (Arduino Mega)	$25.75
Additional Passive Circuitry	$3.05
PCB Fabrication	$55
Housing	$1
Total Cost	$134.80

Appendix B: Code

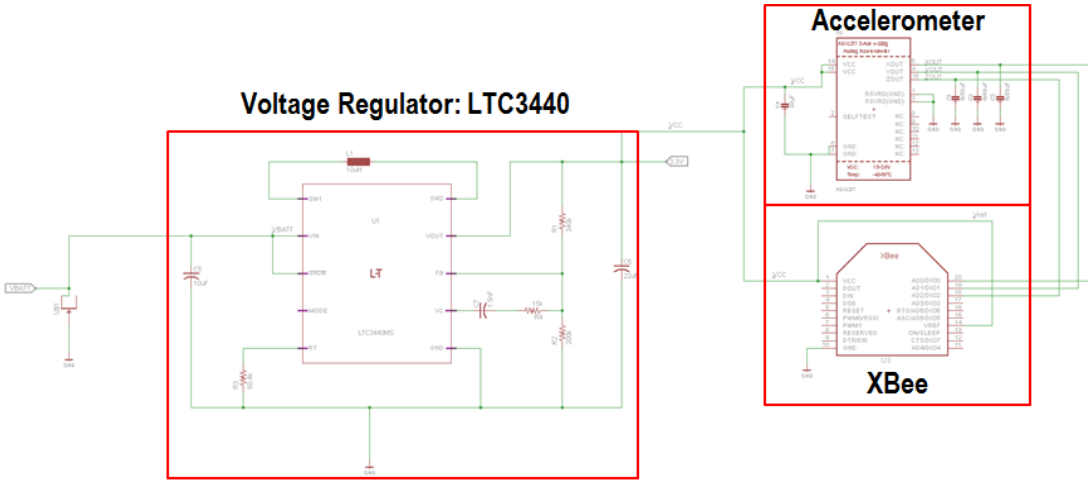
```
#include <SoftwareSerial.h>

int  x, y , z;
byte analogHigh, analogLow ;
float voltageXpin, voltageYpin, voltageZpin;
float gForce_X, gForce_Y, gForce_Z;
float X_scaled, Y_scaled, Z_scaled;
float totalForce;
int i;

//SoftwareSerial xbee(11, 12); // RX, TX



void setup(){
  Serial.begin(38400);
  Serial1.begin(57600);
//  xbee.begin(38400);
  delay(30);
  Serial.println("reading.. ");
}

void loop() {
  readADC();
}

void readADC(){
  // make sure everything we need is in the buffer
  if (Serial1.available() >= 13) {
//    Serial.println(">25 Bytes");
    // look for the start byte
    byte b=Serial1.read();
//    Serial.println(b, HEX);
    if ( b== 0x7E) {
      if (Serial1.read() == 0x00) {
        if (Serial1.read() == 0x0E) {
```

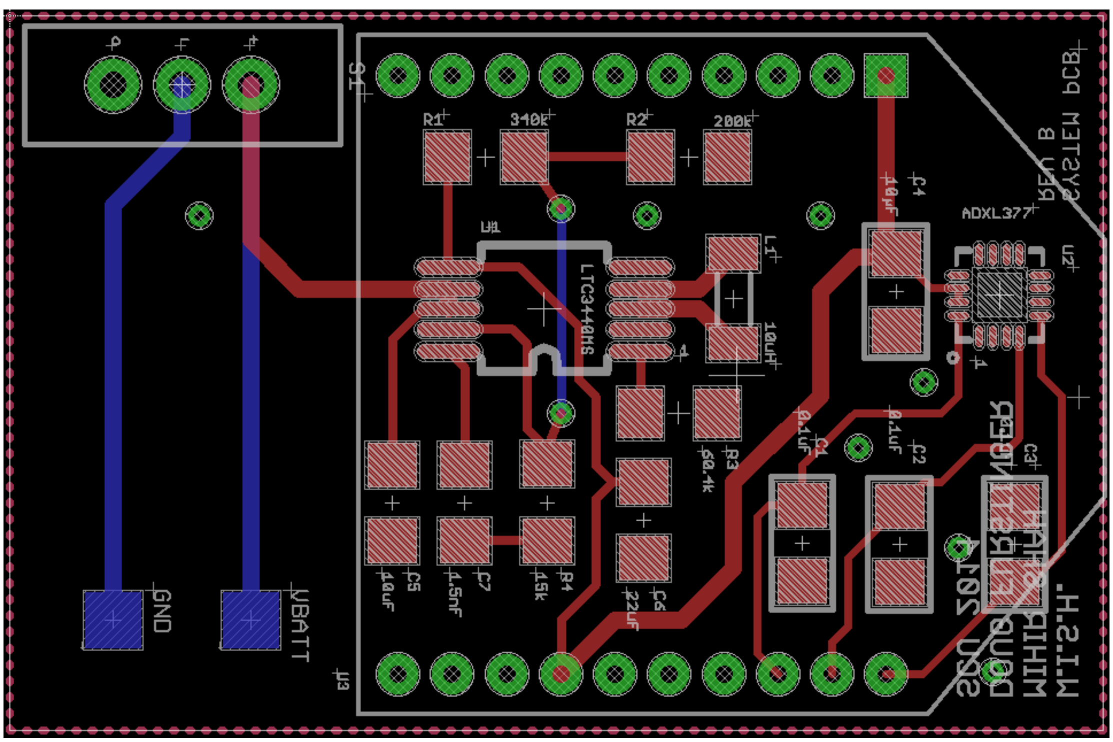
```
      // read the variables that we're not using out of the buffer
//      for (int i = 0; i<8; i++) {
//        byte discard = Serial1.read();
//      }
//      Serial.print("7E 00 0E ");
      for (int i = 0; i<8; i++) {
//      Serial.print( Serial1.read(), HEX);
//      Serial.print(" ");
        Serial1.read();
      }
//      Serial.print(" ----"); Serial.println( Serial1.available() );
//      return ;
    // z-value
    if(true){
      analogHigh = Serial1.read();
      analogLow = Serial1.read();
//      z= analogHigh<<
      z = (analogLow + (analogHigh * 256));
      Serial.print("z-count: ");
      Serial.print(z, DEC);
      Serial.print("\t");

      Serial.print("Voltage:");
      Serial.print(" ");
      voltageZpin = z * (3.3/1023.0);
      Serial.print(voltageZpin);
      Serial.print("\t");

      Serial.print("G-Force:");
      Serial.print(" ");
      if(voltageZpin > 1.65){
        Z_scaled = voltageZpin - 1.65;
      }
      else{
        Z_scaled = 1.65 - voltageZpin;
      }
      gForce_Z = Z_scaled * 153.846;
      Serial.print(gForce_Z);
```

```
    Serial.println();
  }

if(true){
    analogHigh = Serial1.read();
    analogLow = Serial1.read();
    y = (analogLow + (analogHigh * 256));
    Serial.print("y-count: ");
    Serial.print(y, DEC);
    Serial.print("\t");

    Serial.print("Voltage:");
    Serial.print(" ");
    voltageYpin = y * (3.3/1023.0);
    Serial.print(voltageYpin);
    Serial.print("\t");

    Serial.print("G-Force:");
    Serial.print(" ");
    if(voltageYpin > 1.65){
      Y_scaled = voltageYpin - 1.65;
    }
    else{
      Y_scaled = 1.65 - voltageYpin;
    }
    gForce_Y = Y_scaled * 153.846;
    Serial.print(gForce_Y);
    Serial.println();

  }

if(true){
    analogHigh = Serial1.read();
    analogLow = Serial1.read();
    x = (analogLow + (analogHigh * 256));
    Serial.print("x-count: ");
    Serial.print(x, DEC);
    Serial.print("\t");
```

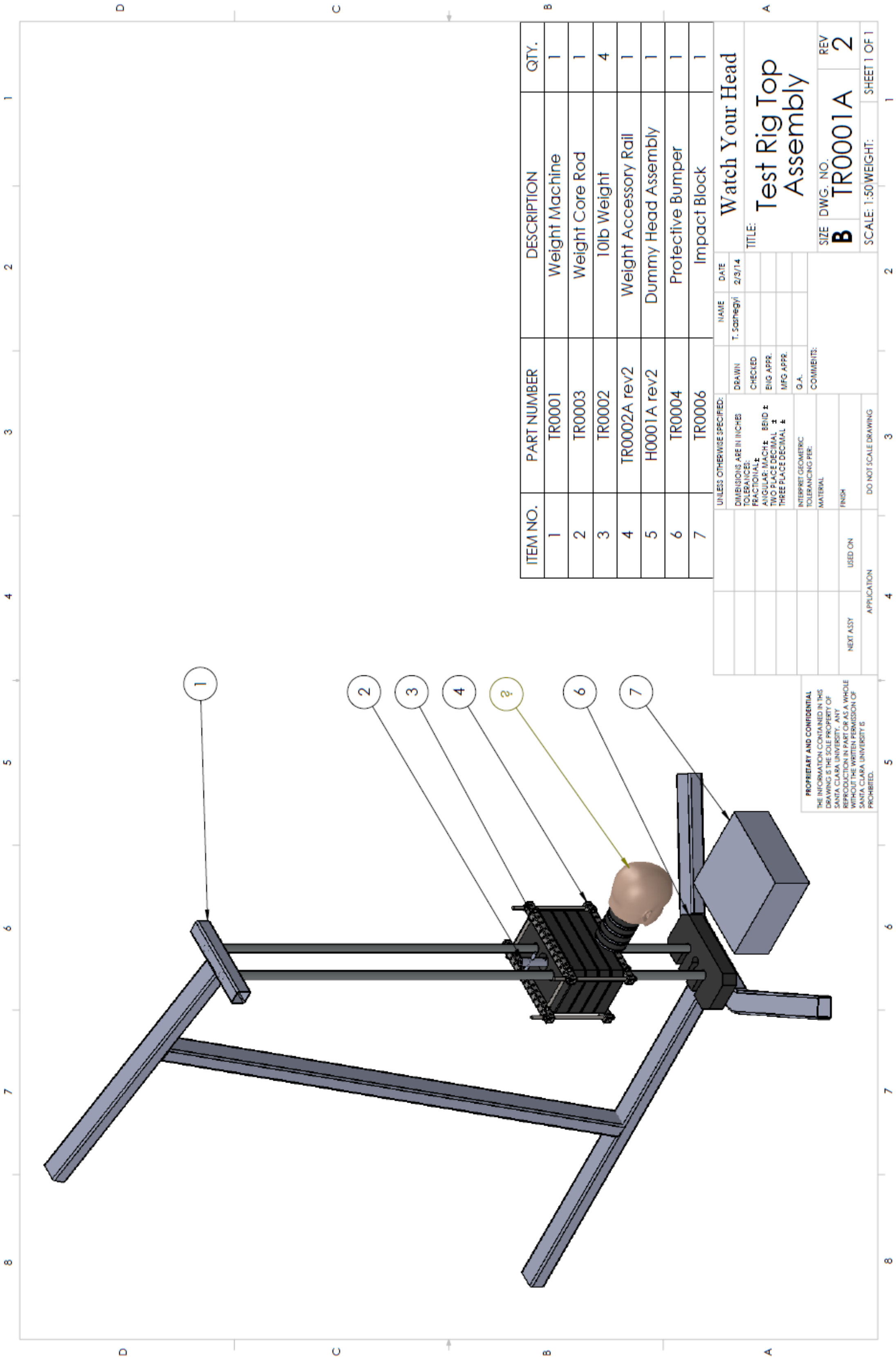
```
      Serial.print("Voltage:");
      Serial.print(" ");
      voltageXpin = x * (3.3/1023.0);
      Serial.print(voltageXpin);
      Serial.print("\t");

      Serial.print("G-Force:");
      Serial.print(" ");
      if(voltageXpin > 1.65){
        X_scaled = voltageXpin - 1.65;
      }
      else{
        X_scaled = 1.65 - voltageXpin;
      }
      gForce_X = X_scaled * 153.846;
      Serial.print(gForce_X);
      Serial.println();
      Serial.println();

   }
   totalForce =
sqrt((gForce_X*gForce_X)+(gForce_Y*gForce_Y)+(gForce_Z*gForce_Z));
   Serial.println(totalForce);
   Serial.println();

   if(totalForce>=10){

   }
   } // got 0x0E
   } // got 0x00
   } //got 0x7E
//   else
//    Serial.println("NO 7E.");
  } //xbee available
} // ADC READ
```

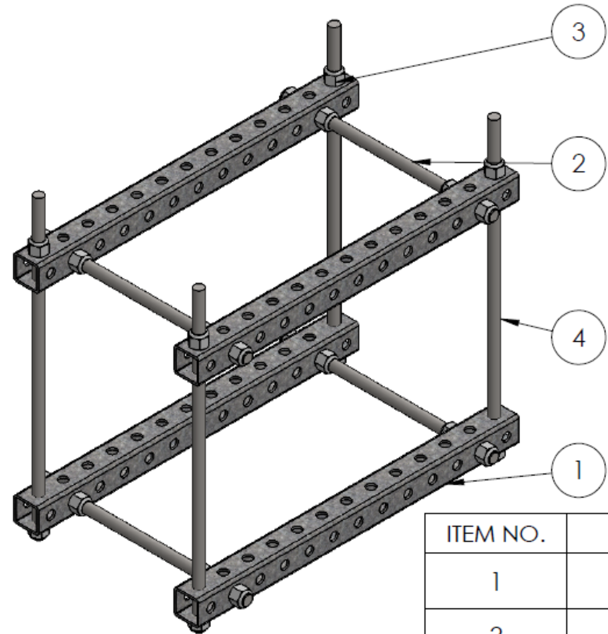
Appendix C: PCB Schematic & Layout





Appendix D: 2D Mechanical Drawings





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	TR0005 rev2	Galvanized Low-Carbon Steel Perforated Tube	4
2	90322A100	Grade 8 Alloy Steel Threaded Rod, 3/8"-16	4
3	90630A121	Grade 8 Steel Nylon-Insert Hex Locknut, 3/8"-16	24
4	90322A100-B	Grade 8 Alloy Steel Threaded Rod, 3/8"-16	4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	T. Sashegyi	3/19/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

NEXT ASSY | USED ON
APPLICATION

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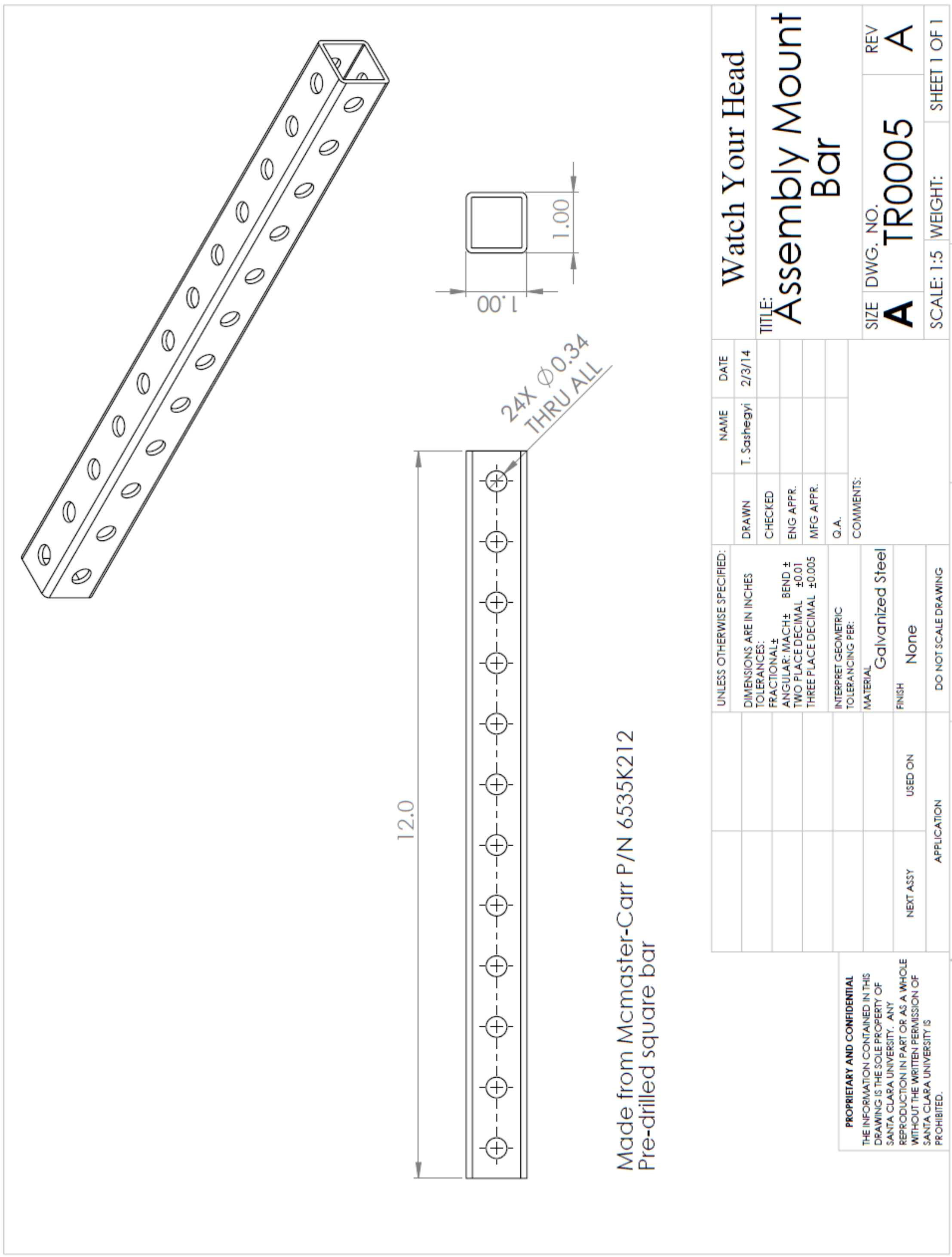
Watch Your Head

TITLE: Weight Accessory Rail

SIZE A | DWG. NO. TR0002A | REV 2

SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



24X Ø0.34
THRU ALL
1.00
1.00
12.0
Made from Mcmaster-Carr P/N 6535K212
Pre-drilled square bar
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Galvanized Steel
FINISH
None
DO NOT SCALE DRAWING
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USED ON
APPLICATION
NAME
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DRAWN
T. Sashegyi
2/3/14
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Watch Your Head
TITLE:
Assembly Mount Bar
SIZE
A
DWG. NO.
TR0005
REV
A
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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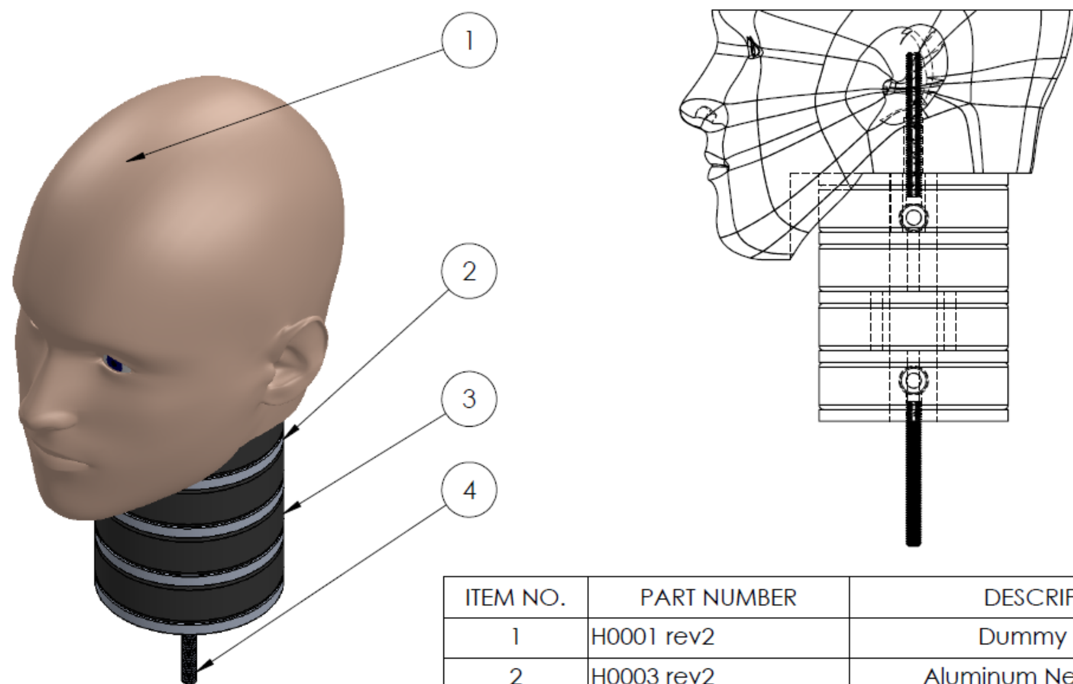

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	H0001 rev2	Dummy Head	1
2	H0003 rev2	Aluminum Neck Spacer	5
3	H0002 rev2	Neck Foam Puck	4
4	3798K38	McMaster-Carr Eye Bolt	2

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NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	T Sashegyi	3/19/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Watch Your Head

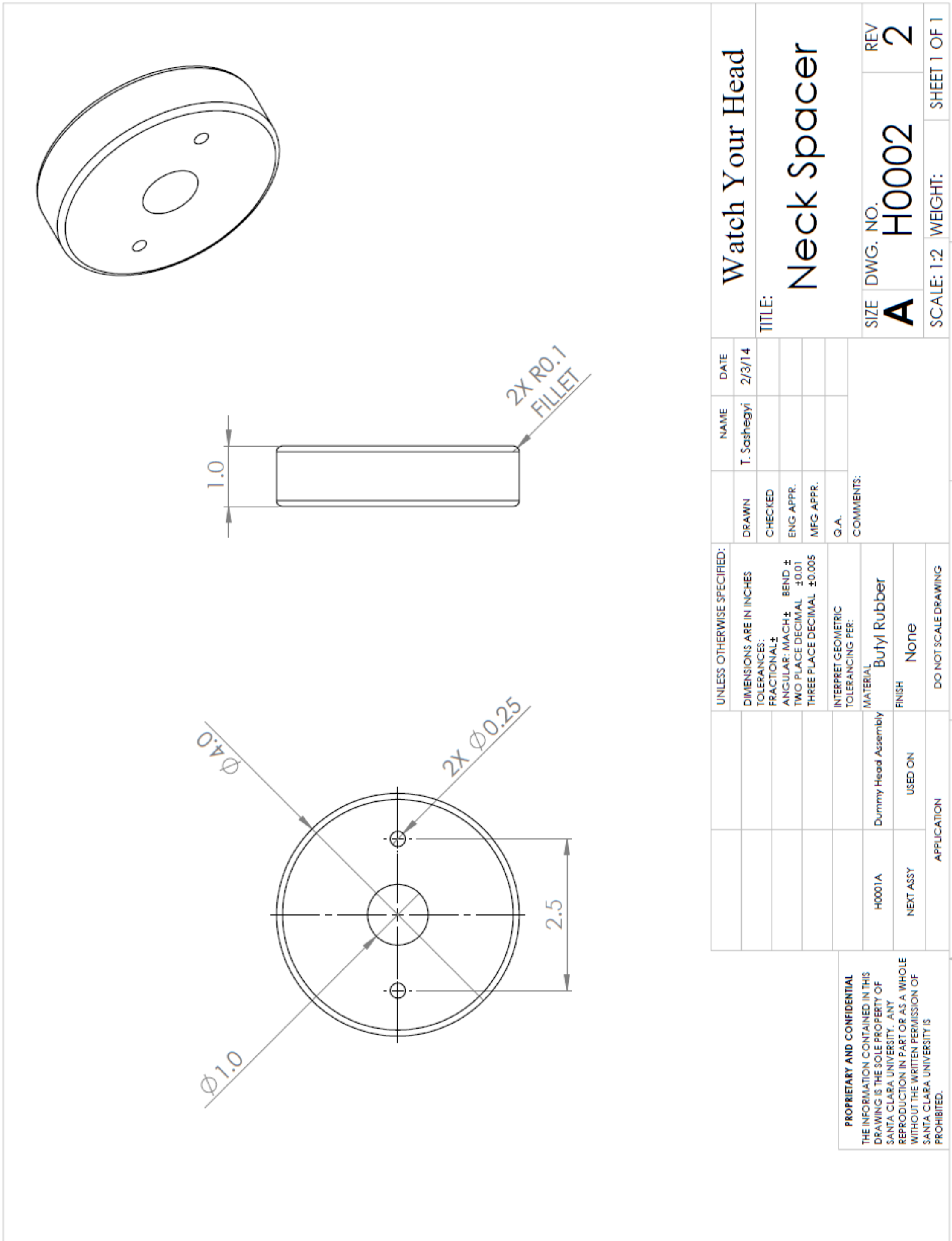
TITLE:

Dummy Head Assembly

SIZE A | DWG. NO. H0001A | REV 2

SCALE: 1:3 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1


2X R0.1
FILLET
1.0
Ø4.0
2X Ø0.25
2.5
Ø1.0
Watch Your Head
TITLE:
Neck Spacer
SIZE
A
DWG. NO.
H0002
REV
2
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
NAME
DATE
DRAWN
T. Sashegyi
2/3/14
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Butyl Rubber
FINISH
None
DO NOT SCALE DRAWING
H0001A
Dummy Head Assembly
NEXT ASSY
USED ON
APPLICATION
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Appendix E: Budget

TEAM	Watch Your Head				
Date	27-Jan-14				
INCOME					
Category	**Source**	**Sought**	**Committed**	**Pending**	**Detail:**
Grant	Dean's fund	$ 800.00	$ 800.00		
	IEEE	$ 200.00	$ -	$ 200.00	
Prize Money	Nike-SCU	$ 250.00	$ 250.00		
	Nike+ Prototype	$1,000	$ -	$ -	
	TOTAL	**$ 2,250.00**	$ 1,050.00	$ 200.00	$ 1,250.00
EXPENSES					
Category	**Description**	**Estimated**	**Spent**	**Pending**	
Dummy Head	Neck Assembly	$ 50.00	$ 20.00		
	Head Assembly	$ 50.00	$ 30.00		
	Components	$ 20.00	$ 12.00		
Headband	Front	$ 20.00	$ -		
	Rear	$ 10.00	$ -		
Headband ELEN	Nike + Setup	$ 20.00	$ -		
	Accelerometers	$ 100.00	$ 50.00		
Test Rig	Frame	$ 100.00	$ 75.00		
	Modifications	$ 75.00	$ -		
	Head Platform	$ 75.00	$ -		
	Impact Platform	$ 75.00	$ -		
	Impact Sensors	$ 100.00	$ -		
Misc.	Safety Buffer	$ 100.00	$ -		
	TOTAL	**$ 795.00**	$ 187.00	$ -	$ 187.00
	Net Reserve (Deficit)		$ 863.00	$ 200.00	$ 1,063.00

Appendix F: Timeline

Nike+ Watch Your Head Team

Work Breakdown

Gantt Chart		**Week**										
Tasks	**Owner**	6-Jan	13-Jan	20-Jan	27-Jan	3-Feb	10-Feb	17-Feb	24-Feb	3-Mar	10-Mar	17-Mar
Test Rig Construction	Tim											
Test Dummy Construction	Nick											
Arduino Programming and debugging	Doug											
Budget Update Due	Doug				X							
Ethics Assignment Due	Ryan				X							
Detail Drawings Due	Nick, Tim					X						
Working Prototype Construction	Mihir											
Infromal Oral Presentation	TEAM						X					
Accelerometer Data Testing	Doug											
Prototype testing	Mihir											
Analysis Report Due	TEAM								X			
Nike+ Video Creation	Nick											
Nike+ Comeption Due Date	TEAM									X		
Formal Oral Progress Report	TEAM										X	
Formal Written Progress Report	TEAM										X	
Assembly Drawings and Revised Detail Drawings	ME TEAM											X
Reevaluate System	Ryan, Nick											
Reevaluate Testing	Tim											
Thesis table of contents and introduction due	TEAM											
Experimental protocol and updated PDS	TEAM											
Senior design conference	TEAM											
Societal/environmental impact report	TEAM											
Thesis draft	TEAM											
Patent Search or Business Plan	TEAM											
Finalize System	TEAM											
Experimental results	TEAM											
Open house [hardware due] (6/4)	TEAM											
Final thesis due (6/11)	TEAM											

24-Mar	31-Mar	7-Apr	14-Apr	21-Apr	28-Apr	5-May	12-May	19-May	26-May	2-Jun	9-Jun	16-Jun
		X										
			X									
						X						
							X					
								X				
									X			
										X		
										X		
											X	

Appendix G: Business Plan

ABSTRACT

The prevalence of undiagnosed head injuries in the athletic world, and their associated health risks, is too great to ignore. This is especially true in non-helmeted sports where the availability of impact monitoring technologies is few and far between. Our team has built a device that can sense and transmit data throughout the majority of the impact range of standard concussions. This system has the potential to help millions of athletes around the world be much better prepared in the event of a potentially life-threatening head impact. However, while our system is able to accurately detect and transmit impact data in real time, we found that additions such as the ability to sample at a much higher rate than experimented with, a more ergonomic design, and a lightweight, durable enclosure would be needed in order for our product to be a viable mass-market competitor. Although the product is not ready for the mass market as of today, it will be a vital part to larger systems used for predictive analytics and more innovative and robust athletic game strategy.

INTRODUCTION

The Centers for Disease Control and Prevention estimate that over 3.2 million concussions are incurred yearly in the USA (West). In 2009, up to 53% of concussions in high school football went unreported (Bartsch). A concussion is a term used to describe a mild traumatic brain injury which can be induced by blunt force or any other violent movement of the head and neck. This type of trauma typically presents itself in the form of lowered cognitive function such as dizziness, loss of balance, and headaches (McCrory).

According to the American Association of Neurological Surgeons, almost 447,000 sports-related head trauma injuries occurred in 2009. This number increased by 95,000 from 2008. The eight activities with the greatest amount of head injuries are listed below in Table 1-1, with the number of injuries being specific to overall head injuries, rather than just the brain.

Table 1-1: A list of the eight activities with the greatest amount of head injuries in 2009. (AANS)

Activity	Number of Injuries
Cycling	85,389
Football	46,948
Baseball	38,394
Basketball	34,692
Water Sports	28,716
Powered Recreational Vehicles	26,606
Soccer	24,184
Skateboarding	23,114

Figure 1-1 below compares the number of concussions per 1000 athletic exposures in NCAA football between the years 2004 and 2012. Although though there is no significant upward trend, it is important to realize that no serious efforts have been made to tangibly address the issue in the past ten years. This is contrary to other safety systems such as the automotive industry and is indicative of a lack of interest in player's health and safety.

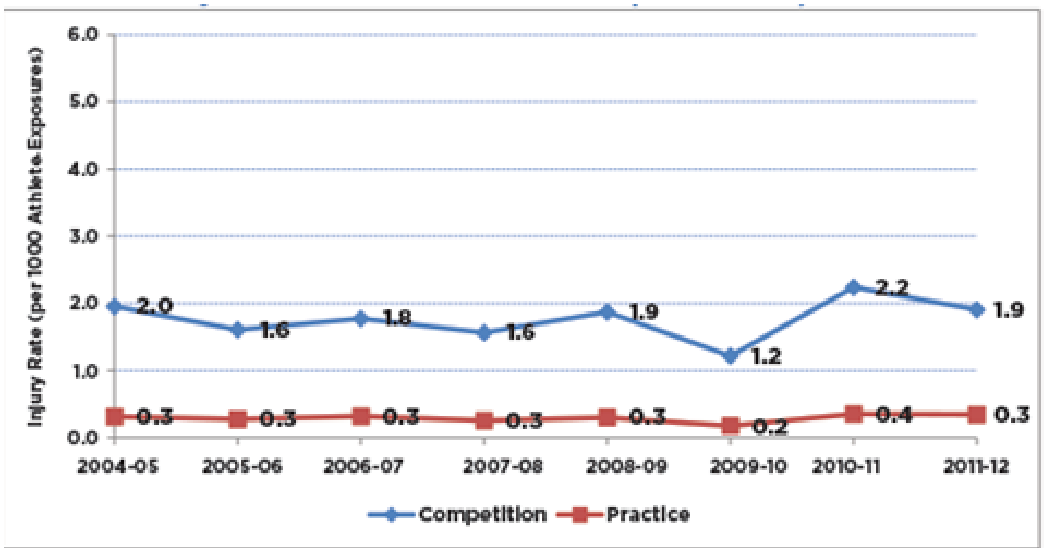

Figure 1-1: A comparison between the average number of reported concussions per 1000 athletic exposures in NCAA football between 2004 and 2012 in competition and practice. (NCAA)

Unfortunately, the current means of actively protecting athletes is mostly outdated and can actually exacerbate the risks. In sports like football, because players effectively wear armor, opponents tend to be more aggressive and consequently hit other players harder and more often. These larger impact forces, and increased number of repetitions, increase the risk of a traumatic brain injury.

According to an interview conducted by our team of the Director of Brain Injury, Department of Neurosurgery at Stanford medical Dr. Odette Harris, MD, MPH, harm associated with repeated concussions can be compounded. Therefore serious and permanent brain damage is much more likely to occur when subjected to multiple concussions without time to heal. Also, the complex medical nature of a concussion entails that there is no single conclusive test that can be used on a playing field to determine the severity of a head injury. Therefore, the difficulty in diagnosing a concussion, in conjunction with the dangers associated with recurrent concussions, poses an alarming issue in the athletic world.

Currently, the only method of detecting concussions on the field is by physical inspection of the player or athlete. However, this first requires that people notice when someone falls or is hit harder than normal. This is not always easy to see, and hard hits are often overlooked in the action. While products do exist that actively monitor potential trauma-inducing strikes, they are part of an emerging market, meaning they are expensive, inconvenient, or both. Worse yet, according to the Co-Director of OSU Sports Medicine's Movement Analysis & Performance research program, Dr. James Onate PhD, ATC, there are no affordable products specifically aimed at youth athletes where monitoring concussions and other mild Traumatic Brain Injuries, or mTBIs, are a primary concern.

It is our Goal as a startup to capture one third of Athletes age 25 and younger, specifically those participating in soccer and basketball.

OUR PRODUCT

Our product uses accelerometers and a proprietary PCB to detect concussions in real time. This data is then sent to a sideline computer where the data is analyzed. If the player incurs a concussion, a warning notification will pop up on the screen to indicate that the athlete should seek medical attention to confirm a possible concussion.

POTENTIAL MARKETS

The target market for our product are amateur athletes 25 years and younger. We anticipate that the primary buyers of this product will be concerned parents, and coaching staff. Our largest market by far would be geared toward high school and collegiate athletic franchises.

CURRENT COMPETITION

There are existing products either in development or on the market which also attempt to provide a solution for the issues suffered by athletes due to head injuries, examples include the Reebok CHECKLIGHT and the X2 Biosystem. These devices do not prevent concussions, nor do they diagnose them; these are tools used to assist in the detection of a concussion, so the athlete can seek professional help. However, they are relatively expensive, do not allow the user to track data in real time, and many cannot be used outside of helmeted sports. The development of W.I.S.H. required extensive review and comparison of the existing products.

MARKETING STRATEGIES

Primarily starting with high schools and colleges would be the most strategic starting position. This would allow us to beta test the device on large numbers of athletes, as well as open up a huge portion of our market to word-of-mouth advertising. If a team can successfully integrate this product into its game time, the team becomes a walking advertisement for the product.

MANUFACTURING PLANS

The product cost can be seen in the table below:

Component	Unit Cost
XBee Series 1	$20.00
ADXL377	$5.75
LTC3440	$2.75
Microcontroller (MSP430 - TI)	$0.45
Additional Passive Circuitry	$1.05
PCB Fabrication	$2
Housing	$0.50
Total Cost	$30.50

These numbers are taken from using a local manufacturer for the PCB's and a injection mold manufacturer for the product housing. Considering labor, the product would be now more than $40 to manufacture. This gives us the opportunity to sell the product for $79.99 making it cheaper than our competitors and still retaining a 200% profit. Warranty for this product would be limited to a 1 year replacement guarantee, not including shipping.

There are currently no investor plans as we plan to do all initial service out-of-pocket. Our private investors wish to keep themselves secret for the time being.

The market reach of this product extends far beyond impact sensing on the playing field. In the future, this product is applicable and useful to the entire athletic community. With an incredibly small design that can be implemented into any sort of headgear, this product has the capability to be in any standard headband or helmet, and not be cumbersome, obtrusive, or dangerous to the user. The product also has the potential to be a key player in future predictive analytics, allowing players and coaches to not only detect and prevent injuries with more accuracy and frequency, but also measure, analyze, and predict progress towards user's specific goals regarding athletic performance and gameplay strategy. This product is the future of sports safety equipment, and once the ball is rolling, there will be no stopping WISH from being on every athletes head.