ME 486C – Smart Helmet

Midpoint Report

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1 BACKGROUND

1.1 Introduction

Injuries occur every day and especially when one plays in any physical contact sports, whether that is from hockey to simply as riding a bicycle. Traumatic brain injuries occur when an impact against the head is taken or rapid movements of the head. These brain injuries can have long-term effects on people. A smart helmet will be able to protect the user as they are playing their respective sport by analyzing the environment and make any preparations to ensure the safety of the person. This task will be done by using sensors to see the oncoming impact and have a sensor harden a specific material as the helmet reads the current situation. At the same time, the smart helmet will be able to collect data of the impact and will be able to be accessed to any personnel of the respective sport. As of now, the team will focus on the American sport, football. This will allow the team to focus on one sport and create a system that will be able to withstand constant impacts and be able to monitor players as they play so any staff can determine the player's eligibility. Once testing is completed, the team will be able to create a smart helmet for any sport.

1.2 Project Description

Following is the original project description provided by the sponsor.

> "Falls, accidents are major causes of traumatic brain injury. Traumatic brain injury occurs due to the impact of the head against objects or rapid movement of the head and can have long-term effects on people. While the major task of a helmet is to protect the head against impacts and constrain its motion to prevent very rapid motions, it should also be able to provide data on performance of the helmet as well as health of the person. A smart helmet should first protect the head against impacts/rapid motion to the best possible, and second can monitor and record the acceleration of the head and the impact forces (upon accident or fall) and based on those data make suggestions to the user. It should also optimize the user's performance in terms of speed, safety and other important criteria. You will design a smart helmet with great protection capability against impacts which will be able to recognize the risk of brain injury by monitoring and recording head kinematics as well as optimize the user's performance. Teams may be tasked with a specific sport in mind or make the project applicable to all sports." [1]

1.3 Original System

This project involved the design of a completely new smart helmet system. There was no original system when this project began.

2 REQUIREMENTS

Chapter 2 contains the customer requirements obtained from the client and the engineering requirements that specify the measurable parameters or conditions of the customer needs. Lastly is the house of quality that is based from the customer requirements and engineering requirements.

2.1 Customer Requirements (CRs)

The CRs of the project are listed as follows along with their weights:

Table 2: Customer Requirements for Smart Helmet

Factors	**Rating Weight**	**Description**
High Protection	5	High protection is listed as the highest weight because safety is the priority of the client.
Similar size of helmet	4	The size of the helmet is a four because the client wants the smart helmet to be similar to those helmets in the current market. No company wants a helmet that is too large and heavy, this does not make sense, so the size of helmet does matter.
Life Expectancy	4	The smart helmet should be able to function as a helmet and last as long as a regular helmet.
More Comfortable	3.5	The smart helmet needs to be comfortable to the user to ensure the safety of their well-being.
Transmit Data	4.5	The client wants the team to be able to collect data of the user and impacts occur during their respective sport.
Small Sensor	3	The size of the sensor matters because the sensor must be able to fit within the interior of helmet and still function
Strong battery	2	A battery will ensure the life expectancy of the helmet.

2.2 Engineering Requirements (ERs)

The ERs of the project are based of the CRs in the previous section. The requirements are listed as follows:

Table 3: Engineering Requirements for Smart Helmet

Requirements	**Description**
Decrease Impulse	During a sudden break during driving, a shock or impulse arises which can potentially cause accidents due to imbalance. The smart helmet will be designed to decrease impulse and control the situation.
Maintain Volume	As stated above "in similar size of helmet" section of customer requirements, users need helmets of normal size and hence maintain the volume of other manufactured helmets.
Increase factor of safety	The smart helmets should be scientifically designed in a way that improves the damage reduction in case of an accident.
Ductility	Ductility is a stretch by a material when a tensile stress is applied to it. The smart helmet should be engineered in a way that does not break or take damage and should show some stretch ability.
Increase power	The customer requirements a strong battery, small sensor, and data transmission (given in Table 2) will increase the helmet's power.
Decrease Diameter	The smart helmet engineered in a way that sensors/wires of any electronic device is less in diameter. These accessories may collide with CR of "more comfortable" but it's needed for a manageable helmet.
Increase voltage	The Smart Helmet designed in a way that the helmet has a "Strong battery" and has the option of amending the voltage for better performance.

2.3 Testing Procedures (TPs)

Testing procedure is a way or method of evaluating the working and functionality of a certain entity. For our Smart Helmet project, the team intended to analyze and specify testing procedures for each of the Engineering Requirements developed by the team in the previous section. Later, use the same sequence of Engineering Requirements in the House of Quality.

The testing procedures for Engineering Requirements are explained below:

1. **Decrease Impulse**
   Conducted experiments to ensure that impulse is decreased in Smart Helmets. For this purpose, put the helmet on a motorcycle-driver dummy and let an accident happen. After this, calculate the impulse values using smart helmet and test the results.

2. **Maintain Volume**
   Tested the volume of Smart Helmets by comparing the dimension with an ideal helmet.
3. **Increase factor of safety**
   After analyzing the results achieved in point 1, increase factors of safety by optimizing and remodeling the helmet.
4. **Ductility**
   Test the stretch ability of helmets by going through different concepts and experiments related to Physics.
5. **Increase power**
   Test and compare different batteries for the smart helmet. In this way, choosing a battery with the highest performance.
6. **Decrease Diameter**
   By going through different design considerations, decrease the diameter of smart helmet technology without compromising the equipment inside.
7. **Increase voltage**
   Conducted different tests so that a solution for highest and accurate voltage required by Smart Helmets.

2.4 House of Quality (HoQ)

House of Quality or HoQ is a device that made an interpretation of the client requirements into specialized descriptors. The HoQ is the most helpful and straightforward apparatus used to change over the client needs into specialized descriptors. House of Quality is a network additionally called Quality Matrix. The matrix gave us subtle elements like client prerequisites, specialized descriptors, need of the different descriptors, connection between the descriptors, target esteems for every descriptor, and so forth. It likewise indicated aggressive assessment between different items with the present item. For the project, the team developed a detailed HoQ, which can be seen in Appendix A,

In the Appendix A, it can be observed that the added engineering requirements (Decrease Impulse, Maintain Volume, Increase factor of safety, Ductility, Increase power, Decrease Diameter, Increase voltage) based on their importance. Similarly, with the customer requirements (High Protection, Similar size of helmet, Life Expectancy, More Comfortable, Transmit Data, Small Sensor, Strong battery) based on their weights and rating by the customers. In the end, the team plotted them and ranked the modules based on their rankings.

House of Quality aided in the project in multiple ways. First, HoQ helped in the team’s decision as the coming up with design solutions which can be seen in chapters three and four. The HoQ enabled the team to choose what is the most important part the team should focus on and how to improve the design to create a new design. The requirements are based from the previous two sections of this chapter. These requirements tell how the team implemented a new system into the smart helmet while remaining to the team’s intention of the client.

3 EXISTING DESIGNS

Defining the project is important to understand the goal, and the requirements for the project. The next step after understanding the project is to learn about existing designs. One approach to designing a new, re-engineered system is to learn about the technology that is currently available before coming up with designs. Information on existing products are found from the internet and through engineering literature. This section contains research on existing designs at the system level, functional decomposition, and subsystem level designs. The system level designs are designs relating to the entire project and help with understanding what technology is available that relates to the project. Functional decomposition consists of understanding the necessary inputs and outputs of the system and the various functions of the project. The subsystem level research helped in gaining a better understanding of various applications of the subsystems of the project.

3.1 Design Research

The process for design research consisted of research through the internet and gaining information from faculty that has experience in topics related to the project. The internet was able to provide information of the smart helmet technology that is currently available. Effective keywords such as smart, sensing, and football helmet were used in the internet research process to help find technology that closely relates to the project. Faculty with a background related to the project were also pursued for the design research of the project. Dr. Hesam Moghaddam who is also the client of the project shared about brain injury threshold information and the importance of knowing threshold values for the project. Also Dr. Ciocanel shared his understanding of magnetorheological (MR) fluid and its application to the project.

3.2 System Level

An existing system level design is one that accomplishes requirements similar to the smart helmet project. The system level design research in the project helps with understanding products that have similar requirements as the project. Understanding similar systems will be useful for coming up with design ideas for the project. Understanding systems related to the project assures that the design is new, and also helps with coming up with creative ideas by building from existing systems. The faults in system level designs is important to know so this project can improve on those faults and avoid them.

3.2.1 Existing Design #1: Vicis Morphing Helmet with Innovative Padding Design

The Vicis company smart helmet took the approach of creating a new padding design for their smart helmet. Their design includes columns of padding instead of the conventional block shape padding that normal helmets have. The columns allow the helmet to flex more than other helmets and absorb more of the impact than typical helmets. Figure 1 shows the section of the helmet that Vicis implemented their smart design of column shaped padding. This is useful to the project because one requirement of the smart helmet is the increased protection and this design satisfied this requirement by doing a simple change in padding of the helmet.

Figure 1: Vicis Helmet

3.2.2 Existing Design #2: Riddell Sideline Response System and Insite Impact Response System

The Riddell Insite Response system is an impact monitoring system for football helmets that uses sensors that go in the helmet to collect data and report the data to the sideline. This system shown in figure 2 allows the player to be monitored during a game or practice session for serious head injuries that exceed a calculated threshold. This system-level existing design collects data from impacts with sensors and shares that data which is directly related the customer requirement for the smart helmet project of implementing sensors to collect and share data from impacts. This design is helpful for the project because the system can be used to help guide the design of the sensors in the smart helmet and the data collection and sharing system.

Figure 2: Riddell Insite Sensor

3.2.3 Existing Design #3: Xenith helmets

The Xenith helmets included a reengineered padding system that moves with the head instead of the hit. The padding reduced the linear and angular forces which is one of the customer requirements for the smart helmet project. They also changed the adjustment system that is more variable and allows players to get a more custom fit that increases the comfort. The Xenith helmet padding design is shown in figure 3.

Figure 3: Xenith Helmet

3.3 Functional Decomposition

3.3.1 Black Box Model

Black Box model is one of the most important technique for the engineering project. Figure 4 shows the inputs and outputs for the smart helmet project. The inputs are based on three main categories such as energy, material, and signal. However, both inputs and outputs should satisfy the customer needs toward the smart helmet project. This project should accomplish many important functions such as comfort materials, lightweight, safety, and smart technology. The team decided to include the elasticity material in the helmet for comfort purposes. Figure 4 shows the elasticity material as input and hardened as output in the black box model. Safety is another important function in customer needs. As a result, the team created the kinetic energy as input and injury as output as discussed in Figure 4. Another important function of the customer needs is lightweight. The team is trying to reach the lightest weight as possible in this design. One way of that is to decrease the weight of the helmet by decreasing the elasticity material. Finally, smart technology is one of the customer needed in this project. As discussed in the Figure 4, the team created a sensor with a smart technology in this project. This customer need helped the team improve the features of the helmet.

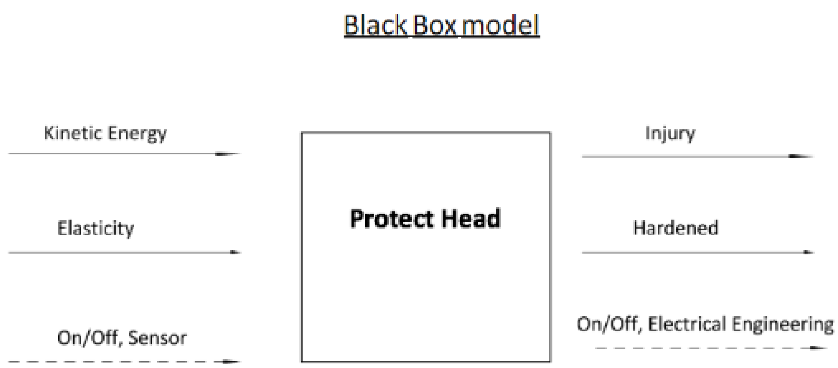

Figure 4: Black Box Model

3.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

Hypothesized Functional model (HFM) is a very useful technique in this project. The main purpose of the hypothesized functional model is to understand the inputs and outputs of the smart helmet. It also gave a detailed information about the design project. The HFM is more of a developed process than the black box model because it breaks the component of the inputs and outputs in detail. Appendix B shows how the components of the customer needs broke down through this project. Appendix B gave the team a brief and detailed ideas about the working process. It helped the team to fully understand how the project works, and what are the main results of this working process. The HFM is a very helpful process for the smart helmet project because it improved the performance of the project. For example, when the team decided to create something, then the team should focus on the results, and the input situation through this design. However, the HFM will help through this situation because it helped the team to know the advantages and disadvantages of the inputs and outputs situation through this project.

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3.4 Subsystem Level

After decomposing the project and understanding the inputs and outputs for the system and the various subsystems involved with the project it is important to look at different existing designs that related to the project. Sensing is a subsystem that is important for the project and was defined in the functional model to be a necessity and have a kinetic energy input and a signal output. The next subsystem that was researched is the controllable padding subsystem that related to the elastic section in the functional model that took in kinetic energy and a signal and distributed the kinetic energy to the head in a safe way. The last subsystem researched is the data transmission subsystem because from the functional decomposition, the sensor is collecting information and there needed to be a way to transmit the information.

3.4.1 Subsystem #1: Sensing

Sensing is a subsystem defined in the functional decomposition for the smart helmet project that takes kinetic energy input and outputs a signal. To gain a better understanding of this subsystem it was important to investigate existing products that involved this subsystem and see how it was applied. Once knowing how other products applied sensors into their design it will be easier to implement this subsystem into the smart helmet design. Sensing was important to the overall project because it is a requirement from the client to include sensors that can measure linear and angular forces the head can experience in an impact.

3.4.1.1 Existing Design #1: Accelerometers in Phones and Laptops

Phones accelerometers sense acceleration forces and applications use it to determine the devices orientation. Some phones have features of going to sleep when faced down, the accelerometer in the phone is used to sense if the phone is facing down. Laptops also use accelerometers to protect itself, there are accelerometers in laptops that can detect a freefall and stop the hard drive in order to prevent it from becoming damaged during the drop. This related the sensing subsystem of the smart helmet project because accelerometers like the ones used in phones and laptops can be used for the project to collect the data required by the client. The client wants the project to collect are linear and angular forces data and this device does both.

Figure 5: Phone Accelerometer

3.4.1.2 Existing Design #2: Motion Laser Sensor Detectors

Laser sensors are essential in buildings that requires security. Nowadays, most security sensors use the motion laser detector. The team decided to include this type of sensor in the smart helmet project. The main purpose of this sensor is detecting the motion of any movement in a particular range. The motion laser sensor works using programmed codes. One of the most common programming code kit is Arduino and using Arduino, the team will be able to detect any type of motion in the football game. Ultrasonic included in the Arduino is very useful device for detecting the distance of the players. The team will use this device to help the laser performance in the smart helmet project. Safety is one of the most important customer needs in this project. As a result, the team will be able to increase the safety with this specific type of system. The laser sensor will be programmed based on the Ultrasonic device that detect motion. Thus, the motion laser sensor will sense any kind of motion in a specified distance. In addition, the team can use the PIR motion detector which is included in the Arduino kit as well. The purpose of this advance device is to detect any motion for a specified range. This device can be alternative for the Ultrasonic device. The team can use either one of those devices. Moreover, most of the cars use this motion laser sensor that detect any movement. The team can also use this device for the smart helmet project by maximizing and minimizing the ranges of the programmed codes. Overall, a motion detector sensor is an improved device that can assist the smart helmet project.

3.4.1.3 Existing Design #3: XOnano Smart Foam Sensor

The XOnano smart foam sensor is a sensor imbedded in foam to be used in applications similar to the smart helmet project. The company's initial product was a smart foam football helmet that transmits data in real-time. The smart foam measures the impacts and pressure while not sacrificing the comfortability aspect of the application. This product relates to the project because comfortability and sensing is a customer requirement for the smart helmet project and this design accomplishes both requirements.

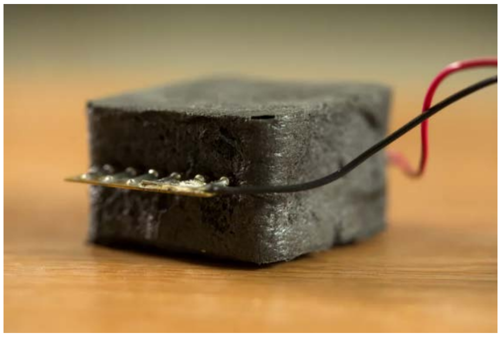

Figure 6: XOnano Foam Sensor

3.4.2 **Subsystem #2:** *Variable Padding*

The variable padding subsystem is the part of the smart helmet that allows for controllability of the protection in the helmet. An example of padding that allows for variability is ferrofluids that have a stiffness that can change and sometimes be controlled. The controllable padding subsystem satisfies the customer need of implementing a smart and innovative technology into the project while increasing the protection of the product. After analyzing system level designs that collect data from a collision and transmit the data, it is important to keep the project unique by being innovative and this subsystem keeps the project innovative.

3.4.2.1 Existing Design #1: Audi Magnetic Shock Absorber

A shock absorber is used to dampen the forces felt on the car from the uneven ground and Audi was able to implement a controllable fluid called magnetorheological fluid into the system. Figure 7 shows a diagram of the shock absorber and how it implements the MR fluid into the system. This existing design relates to the subsystem of the project for a variable padding because this fluid is used as a variable padding for the shock absorber. A shock absorber is constantly moving up and down while a car is moving, and this relates to the smart helmet project due to football players constantly experiencing impacts to the helmet. .

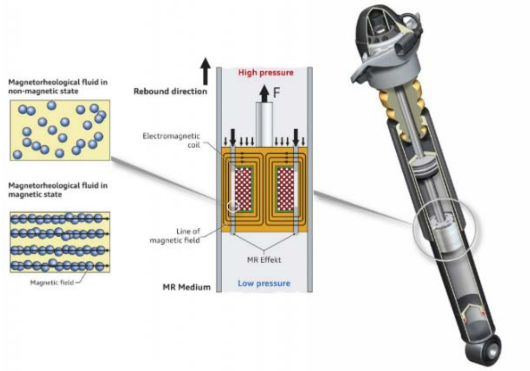

Figure 7: Audi

3.4.2.2 Existing Design #2: Automotive Airbag

Cars are equipped with airbag systems that manipulate the impulse equation by increasing the time an impact occurs so that the forces the driver or passengers experience will be decreased. This system effectively increases the safety in cars and has a similar functional decomposition as the smart helmet project. The airbags inflate rapidly on impact as shown in figure 8, and slowly deflates throughout impact to absorb some of the forces. This relates to the smart helmet project because in both cases there are impacts and a decrease in the forces exerted on the user is required. Airbags could possibly be implemented into the smart helmet project because the system works but needs to be manipulated to work in the application of a smart helmet.

Figure 8: Deployed Airbags

3.4.2.3 Existing Design #3: D30 Armor

D30 is a polymer that provides protection when quick high forces are being applied to it as shown in figure 9 and is soft when there is a force being applied for a long time. This relates to the smart helmet project because it can be used as a padding for the helmet and provides variability compared to conventional foam helmets. This armor is currently used in padding for sports and is effective in protecting players during collisions. The D30 material isn't controllable but based on the process of making this polymer, the variability can be set based on the needs of the application.

Figure 9: D30 Material Protecting Hand from Hammer

3.4.3 Subsystem #3: Transmit Data

Transmitting data is related to the customer requirement of making the data collected from the sensors available to be analyzed. The functional decomposition of the project also shows that after the sensor collects the data, the next function of the device is to transmit the signal from the sensor to another device that will process the signal. Transmitting information is an important subsystem of the project because the data collected would be useless in the case that it can't be moved.

3.4.3.1 Existing Design #1: Phone Applications

Most people nowadays have phones on them that have numerous apps that transmits data. For example, there are phone applications that have maps and shows the data relating to the location of the phone. Phones are easily accessible and there are many apps made for them to transmit data. This relates to the subsystem of the smart helmet project of transmitting information because this design is commonly used and is readily available for most people. Figure 10 shows a phone with apps that transmit data.

Figure 10: Phone Applications to Transmit Data

3.4.3.2 Existing Design #2: Car Bluetooth connection with Phones

Bluetooth is used in many applications and are commonly used in newer automobiles allowing the driver to listen to their music and make calls with the car from their phone through a Bluetooth transmission as shown in figure 11. Newer car models also display the information from the phone about what song is playing or who is calling. This relates to the subsystem of the project relating to transmitting the data from the sensor because Bluetooth in cars effectively transmit data from a phone to the car without wires connecting the two which is what is wanted in the smart helmet project. The functional model does not display an input of wires for the transmission which means it is necessary to have a form of wireless transfer of data and Bluetooth does this effectively.

Figure 11: Car Bluetooth Transmission Example

3.4.3.3 Existing Design #3: Live Streaming from Websites

The last existing design for transmitting data is website streaming. There are many websites that transmit data such as Twitch, which streams live video of people playing video games. These websites are effective at allowing people to follow and watch their favorite gamer live. This relates to the project because the data collected from the sensors of the smart helmet could be projected live onto a website where people can stream in and keep updated on the players condition. Figure 12 shows the Twitch streaming website.

Figure 12: Video Game Streaming Website

4 DESIGNS CONSIDERED

After understanding, asking and researching, the team created the concepts that could help the team to reach the goal. Each member came with two ideas, so the team had ten designs to help to get the job done. All the ideas have put in Pugh Chart that can find in Appendix C. After voting, adding all ideas in Pugh Chart, and discussing relationship between the designs with customer needs, the team have known the successful design that has most positive relationships with the customer needs.

4.1 Design #1: MR Fluid Two

Magnetorheological Fluid two is helmet that comes with sensor contacting with Arduino, and MR fluid which can help to control the viscoelastic. The way that the helmet works is using sensor to know the motion and distance. By defining the distance, Arduino will save data and active MR fluid and viscoelastic to be formed correctly by becoming solid or flexible depending on the collision. MR Fluid two design has two negative relationships with customer needs which are lightweight, and affordable. The reasons why these negative relations exist for this project is MR fluid which is heavy and expensive. The design has three positive relationships which are controllability, safety, data collection. By having MR fluid, the controllability of helmet will be easy by control the viscoelastic after getting the distance between the players, so that will increase the safety of the players from injuries. The design can find in figure 13.

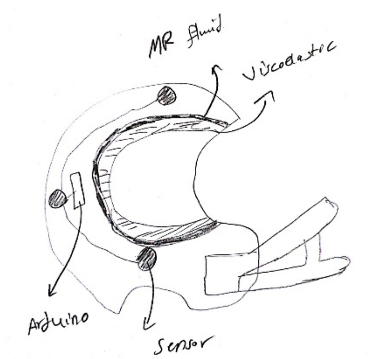

Figure 13: MR Fluid Two Concept

4.2 Design #2: Transferring

Transferring is helmet that comes with sensor, transferring data, and viscoelastic. The work for this helmet is starting with the sensor that contacting with the part of transfer data, so the coach will know players' movement and cases of injury. Also, this helmet comes with viscoelastic that can protect the brain during collision. Transferring helmet has three positive relationships with customer needs. First, this design has lightweight because it is coming without any kind of heavy solid or liquid as MR Fluid two design comes. The cost of the design is not expensive as some of other designs, so that makes the relationship with affordable be positive. Because the transferring helmet does not come with kind of smart ways, the helmet will look better which make the relationship with appearance be positive. In other hand, transferring design has difficulty of controlling the viscoelastic and transferring data which makes negative relationship with controllability. Without having the control of viscoelastic and transferring data in a large percent, the team will not have secure safety, so the team will not hit targets. The design can find in figure 14.

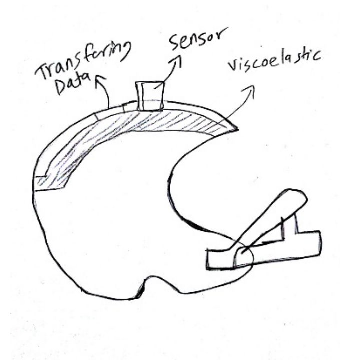

Figure 14: Transferring Design

4.3 Design #3: Airbag

Airbag is the design that has sonar, data collection, and airbag behind section of shell. When the players will start the game, the sonar will feel the body that around each player with determine how strong collision is, so the airbag can dilate correctly depending with collision' cases. The expansion of airbag will be outside of the helmet which reduce the severity of the collision and come back to the helmet normally after protecting the brain. Airbag design has four positive relationships with customer needs. Because it will come with airbag which means it is using gas without having solid or liquid, the helmet is not be heavy. In addition, it is simple design which will help to not pay as other designs, so the relationship with affordable be positive. Airbag is the design that has a large percentage of protection that the team is looking for, the design gets positive rapport with the safety. The design is easy to control and save injury information when it is using the sonar, it ended with positive with controllability as well. However, when the design is protecting the players by using the airbag, the design will not look normally which makes negative relationship with appearance. The Airbag design can found in figure 15.

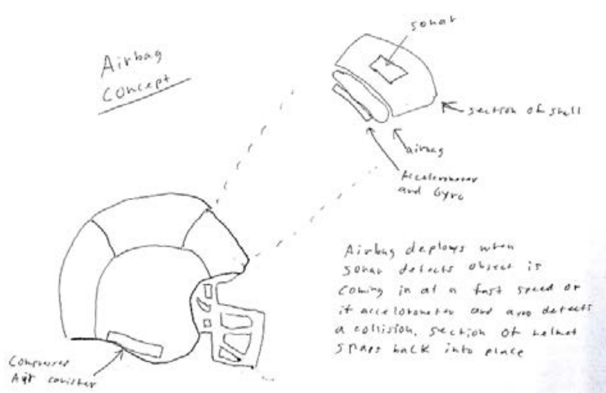

Figure 15: Airbag design

4.4 Design #4: Suba Diving

Instead of creating a helmet with an iron material attached to the football helmet, the team created a design with a very light weight. The main idea for this design was mixing up the scopa diving's stretched suite with the football helmet. The scuba diving suite is a very starched material because for the movement of the diver in the ocean. Scuba diving suite can also absorb the sweat from the diver's body. As a result, this design is talking about attaching the scuba diving suite to the football's player head. Moreover, scuba diving suite observed the strong movement in the body. Thus, this stretched material can absorbs the strong movement in the player's head. The advantages of the scuba diving helmet are comfortable material, light weight, less expensive, strong movements absorb, and sweats absorb. On the other hand, the disadvantages of this design are skin sensitivity and having an allergic to this specific material. Thus, the scuba diving has three positive relationship with the customer needs which are lightweight, appearance, and safety. The affordable, controllability, sensing are the three-negative relationship with the customer needs. The design can find in figure 16.

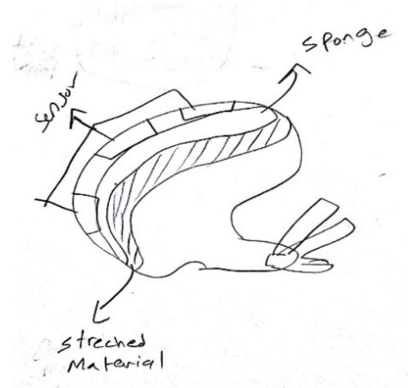

Figure 16: Scuba Diving

4.5 Design #5: Boxing Helmet

The main idea of this design was to mix up the boxing helmet with the football helmet. The shape of boxing helmet is square, and it's attached with a very comfortable material. This comfortable material can absorb the hit from other players. However, the idea of this design is creating a smart helmet for a football player's that has this comfortable material. The football game has a lot of hits and strong movement during the game. As a result, the team decided to create a movement detector that can absorb the motion of the players without any sound. This sensor will absorb the hit before it comes to the smart helmet without knowing the players. The advantages of this design are comfortable material, movement detector, and strong hits absorber. The disadvantages of this design are heavy materials, expensive materials, and long materials that might not be able to fits the helmet. Thus, the boxing helmet had two positive relationship with the customer needs which are safety and appearance. In other hand, the design ends with four negative relationship with the customer needs which are lightweight, controllability, sensing, and data collection. The design can be found in figure 17.

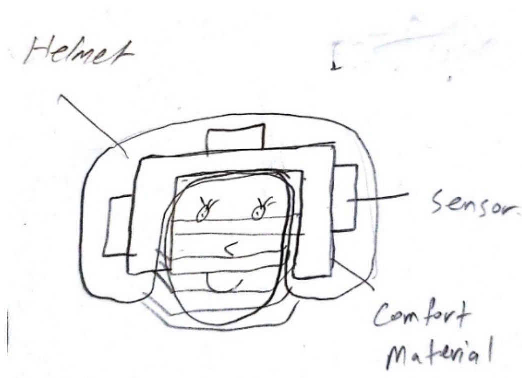

Figure 17: Boxing Design

4.6 Design #6: Transforming

This idea designed based on Transformers movie. In the film, the cars transform into robots or machines. Hence, this smart helmet is a transforming helmet which decrease the hit of the players. In football helmet, many players get a vibration effects because of the strong hits. In this design (which can be seen in figure 18 below) the hit will almost be neglected because of the transforming feature. In more details, when a player hit this helmet strongly, then the transformation feature in the helmet will occur fast if the hit was strong enough. On the other hand, the hit of the players will occur really slow if the hit is not strong enough. The objective of this smart helmet is to decrease the hits of the players and transforming the hits of the players. The process of transforming the hit is to absorb the shock force from the players and transform it from one state to another state. For example, if the car hits another car, then the damage of the car should be fixed. However, in this design the damage of the helmet will be fixed by transforming the helmet into new state. In this new state, the damage of the helmet will be almost neglected. Therefore, the transformation feature will improve the performance of the helmet because of observing more and more hits.

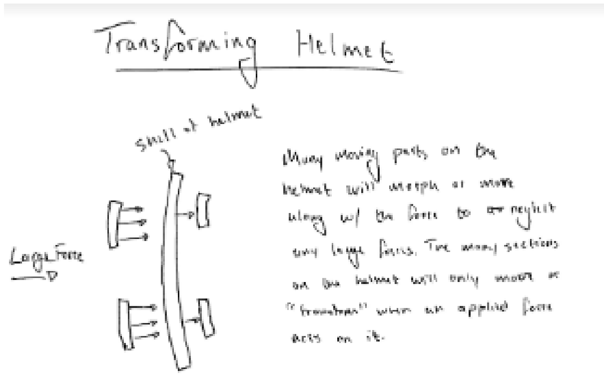

Figure 18: Transforming Design

4.7 Design #7: Columns of fluids

This design consists of sensors and MR fluids. The sensors have many objectives such as detect the incoming impact speed, and another sensor is to detect the helmet speed. With the linear acceleration data from the accelerometer, the team will be able to record the data of the upcoming hit. Furthermore, the ultrasonic sensor will detect the distance between the smart helmet and the other players. However, with this design the padding attached in the helmet will provide fluid to the players. The MR fluids column will help in increasing the safety of this project because the coach and the player will identify any major injuries in the football game.

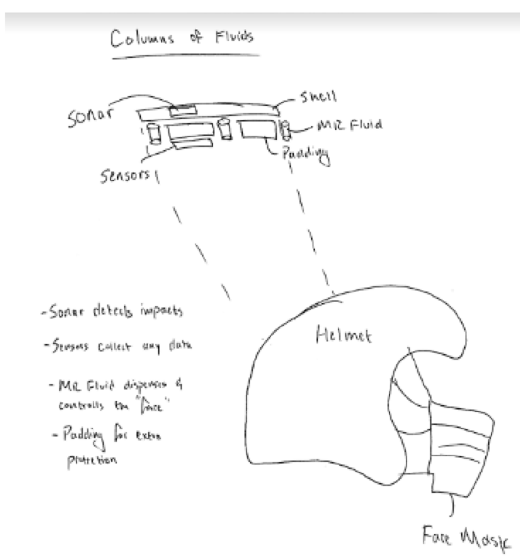

Figure 19: Column of fluids design

4.8 Design #8: D30 Helmet

Some companies are using D3O material with motorcycle gear such as the jacket. Hence, this D3O helmet designed based on that idea. The main idea of this design is to absorb the shock force with using comfortable materials such as D3O material. The main objective of this design is to convert the hit of other players into comfort situation by absorbing the shock of the hit. In more details, the D3O will expand with no hit situation. However, the D3O material will compress into rigid body with strong hit. This strong rigid body will save the head from getting a serious injury in football field. The upper side of the material is rigid, but the internal part of the D3O material is soft for the players head.

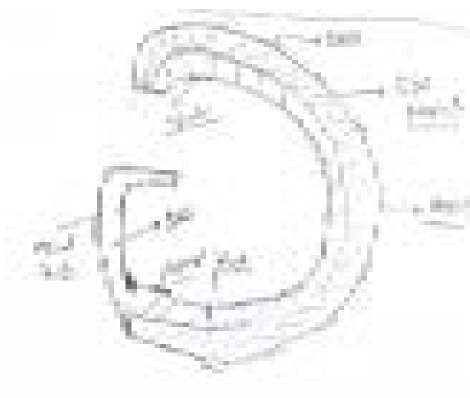

Figure 20: D3O Helmet

4.9 Design #9: Vibration Helmet

The team generated this idea from the vibration movement. In the football field, many vibrations occur due to the strong hits between the players. However, the main idea of this design is to convert and absorb the strong hit into a comfort situation. This design is basically consisting of light, sensor, D3O material, sponges, and metal fence. The light is attached to the upper part of the helmet. The main objective of this component is to decrease the process of saving players on the football field. The light will notify the coach and the other players of the serious injury. Hence, the player will be secured quickly. Another objective of this design is to have more than one comfort material to increase the comfort of the player. The only disadvantage of this design is the weight, which is far more than expected because of adding more than one material into it. The two materials are sponge and D3O materials.

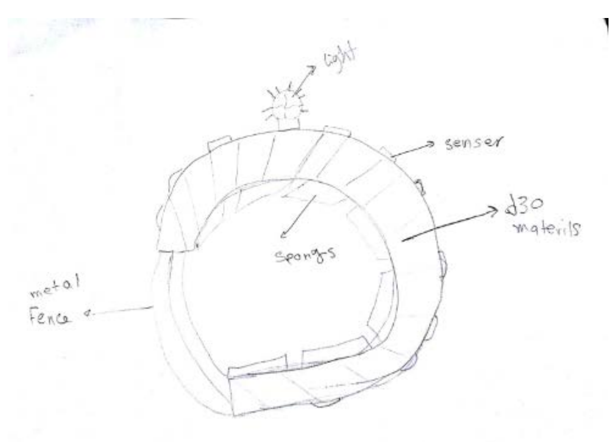

Figure 21: Vibration helmet

4.10 Design #10: Padding of Helmet

This design looks more into the inside of the helmet and explores one variation of how the padding can be displayed to provide protection and comfort at the same time. As seen below in figure 22, the padding design will decrease the amount of force as the force reaches closer to the head. The padding will implement the MR fluid in the middle to absorb most of the force impact, the viscoelastic material will be part of the padding to assist with the MR fluid. The viscoelastic material is added because the fluid is too dense, thus making the fluid heavy, so the viscoelastic will act along the fluid to absorb any forces. The foam is essentially part of the padding, the viscoelastic will be integrated with the foam.

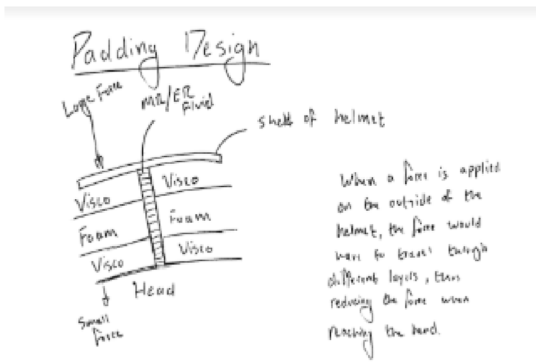

Figure 22: Padding of Helmet Design

5 DESIGN SELECTED

Chapter 5 contains the rationale for design selection below that described the reasons for choosing one of the possible solutions to the project. The rationale for design entails the selection of possible solutions from the generated Pugh Chart and Decision Matrix. Details of the advantages and disadvantages is given to justify the one possible solution.

5.1 Rationale for Design Selection

The selected design solution will be the utilization of the MR fluid while incorporating the D30 material and laser sensors. The process of choosing the final solution derived from the Pugh Chart, which can be seen in Appendix C, and the design was set as the datum. While the other concepts from Chapter 4 were compared to the MR fluid, the top three designs were then selected and compared in a Decision Matrix as seen in Appendix D. The MR fluid design scored the highest out of all because the design will enable the team to do two main functions. The first main function allows the team to please the client's needs as their main objective is to have data collection of impact forces of the user. The second function is making the smart helmet "smart" by implementing a system that will enable the helmet to detect oncoming impacts and make any preparations for the impact, i.e., the MR fluid being activated with a magnetic field and allowing the helmet to change the stiffness of the padding.

5.2 Design Description

The smart helmet design consisted of a helmet shell with viscoelastic material mounted in the shell to be used as the padding. The Arduino Uno board was used along with a laser, linear accelerometer, and also a gyroscope sensor. A Bluetooth transmitter connected to the Uno board transmits the sensor readings to a Bluetooth paired device such as a phone or laptop. Magnetorheological fluid was an idea to increase the protection of the helmet but after researching the material, the team decided it wasn't feasible for the project. It was found that an accelerometer with a range of at least 100 g's will be necessary for the project to be able to determine if the smart helmet user has surpassed concussion thresholds.

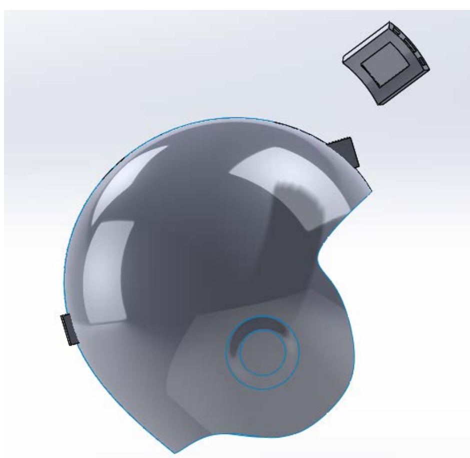

Figure 23: Exploded View of Shell and Section of Padding

Below is the section where each team member did an individual analysis and how each relate to the project and how the research influenced the project.

Linear Acceleration

This assignment talks about the linear acceleration calculation of the smart helmet project. Safety is one of the most important customer needs in the smart helmet project. Thus, calculating the linear acceleration will help in increasing the safety of this design. Knowing the input and output acceleration of the linear acceleration will help the team to recognize the g force required of this design. In more detail, If the team identifies the g forces data from the accelerometer then the forces of the player can be calculated as well. Valid setup is where the team write the codes that goes only one time. On the other hand, the valid loop is a place where the team writes the codes that run again and again. The input of this codes was made in the pinMode code. This code helps identify what goes in or out the Arduino codes. However, analogRead is a code in Arduino helps to read the voltage input from the basic board in Arduino kit. Serial print codes are where the x, y, and z axes are printed in the linear acceleration data. The Approximated voltage range used in this code was between 0 to 5 volts.

Magnetorheological Fluid (MR fluid)

The next individual analysis researched was on evaluating the feasibility of implementing MR fluid as a smart padding for football helmets. The volume allowed was calculated based off of requirements of the client. Research on ways to apply the MR fluid was found in the analysis but exact dimensions weren't able to be calculated due to the numerous dependent variables in the equations found. In order to get exact dimensions for the MR fluid application, more research and testing would need to be performed to define some of the variables and isolate the dimensional variables. The factor of safety was estimated and although it is higher than most engineering factors of safety for machines and other designs, a higher factor of safety is needed for this project due to the fact that a parameter for the project is to protect the human brain. To implement MR fluid into the smart helmet project, testing would need to be done for the control ratio and mechanical power in order to be able to calculate dimensions. After analyzing the MR fluid and judging by the time constraint of the project, this material doesn't seem feasible for the smart helmet capstone project but could possibly be useful for other dampening applications where weight and time of the project isn't a constraint.

G-Forces

The individual analysis that was researched was the effect of linear acceleration on the head and how fast a person needs to stop to cause a concussion. There was a need to calculate the g-forces because there is a range of g-forces an individual can endure before receiving injuries to the head such as concussions. The range for a possible brain injury occurs between 50 - 100 g-forces. A relationship between linear acceleration and g-forces can be found by using the gravity of Earth. Making some assumptions that are based off professional football players, the results of the data showed that the amount of g-forces a player takes varies on fast they are stopped on impact. The data showed that less than 0.02 seconds causes higher amounts of g-forces. From the results, the team would be able to compare results of future data and better understand the effects of linear acceleration

Type of sensors

The constant development in engineering and material science has resulted in the creation of sensors. These sensors are classified in different categories which include; pressure, radar, proximity and laser sensors. The project in question is about selecting the best type of sensors that can be used when developing a smart helmet. All these types of sensors have their own ideal places of application.

The working principle of a laser sensor makes it ideal for the application in creating a smart helmet. It uses a simple technique of triangulation but instead of sound like the radar sensors it uses light. The triangulation sensor gives the exact distance that is being measured. Even small distances or long distances. Light is emitted from the laser and is directed to the object where the reflected light is focused on the lens. The lens collects the light and is always located close to the emitter itself. Using the linear array camera, the spot created is focused on it (Staff). What the camera accomplishes in this type of thing is to focus it an angle of approximately 45 to 65 to the center. The image that is created from the spot is then analyzed and measured to determine the distance in question. For a smart helmet this technology is ideal, and it can help save injuries. It is effective because it is fast and quiet during operation. Its sensitivity is very high and that is why it gives exact results that is needed. This assures the users to be aware of the dangers before they can even happen. Smaller distances are also measured with a high level of accuracy.

Viscoelastic Material

D3O is an impressive material which can be used in anything to make it efficient in its absorbing capabilities. With the usage of D3O impact protection shock absorbing material, the absorbing capability of the products by the usage of this material can not only be increased to an optimum level, but its response to the large impulsive forces is impressive as the mechanism is designed at a molecular level makes it stronger when a force is applied. However, D3O materials behave as normal material when free from any influence of force but when an impulsive external force is applied, the molecules are locked together and absorbs the energy imparted by the external impulsive force while it also makes the material stronger as the molecules are locked and the stress bearing capacity of the material is enhanced. The material follows the Prony series approach for viscoelasticity which determines the behavior not only for the relaxed state of material but also when force acts on it.

6 Proposed Design

The team will implement the design by making a physical change in a current system as well as writing code to helmet to make the helmet “smart”. In Appendix E, the figure shows how the team will manipulate the shell of current football helmets to mount the laser sensors. More research is necessary to find more specs on laser sensors that will fit this application and once the sensor is chosen the dimensions for the sensor will be adjusted in the design. Appendix F shows a drawing of the padding design for the smart helmet. Slots through the foam are going to be cut out to apply the viscoelastic material to improve the absorption of impacts. Another section will be cut out to fit the accelerometer, and it is placed on the inner side of the padding closest to the head to record accurate data.

Bill of Materials

The team has conducted the economic analysis that can be found in Appendix G. The total cost of smart helmet is known. The parts that the team needs to build the smart helmet are listed in Appendix G. The bill of materials displays the part numbers, component description, how many pieces needed to have for each component, what is the cost with the reference that the team used to know how much each part cost. The material that would go into the smart helmet are battery, D3O, laser sensor, Arduino, data memory, RTCSD-01, parts of Bluetooth, Axis accelerometer and Gyroscope. By having the Economic analysis, the team found the total cost of smart helmet design that would be $352.51.

Schedule

The Gantt chart helps to divide the work among the team equally. It helps the team to know when the deadline of assignments is, so the team can finish each assignment before the due date. As seen Appendix G, the chart comes with task name, start date, the due of the assignments, assigned to, what percentage done, time spent for each part of the assignments. All that comes from the Gantt chart which can find in Appendix H and I. Also, the schedule for upcoming semester spring 2019, ME 486C course plan can find in Gantt chart in purple bars.

7 Implementation

7.1 Manufacturing

Manufacturing the smart helmet, the team started with a helmet shell by removing the padding that came with the helmet. The Arduino sensors is the smart portion of the helmet. An Uno board, accelerometer, gyroscope, laser sensor, microSD breakout board, and Bluetooth transmitter are wired together that will be the electrical components mounted to the helmet. The compiled code for the electronic parts will need to be downloaded onto the Arduino Uno board. The harder D30 viscoelastic material will be mounted in strips using Velcro inside the shell to replace the old padding to improve the safety of the helmet. The softer D30 will be mounted using Velcro on top of the harder material for more protection and comfort. Also, an app will be needed to be downloaded onto a Bluetooth enabled device, such as a phone, to connect to the smart helmet and see the sensor readings. The sensor readings will also be saved onto a memory card as a backup in the case that the Bluetooth transmitted data wasn't received from the separate device.

The testing device for the helmet is based off of an ASTM testing method and was built using a sheet of plywood, two by fours, screws, and a hinge. The plywood is for the base and the wall of the testing device, the two by fours are used as the supports for the wall, another two by four is used as the arm that the helmet will be mounted to, the hinge connects the two by four arm to the plywood wall, and screws hold it all together. Figure 24 shows the 3D model of the testing device built.

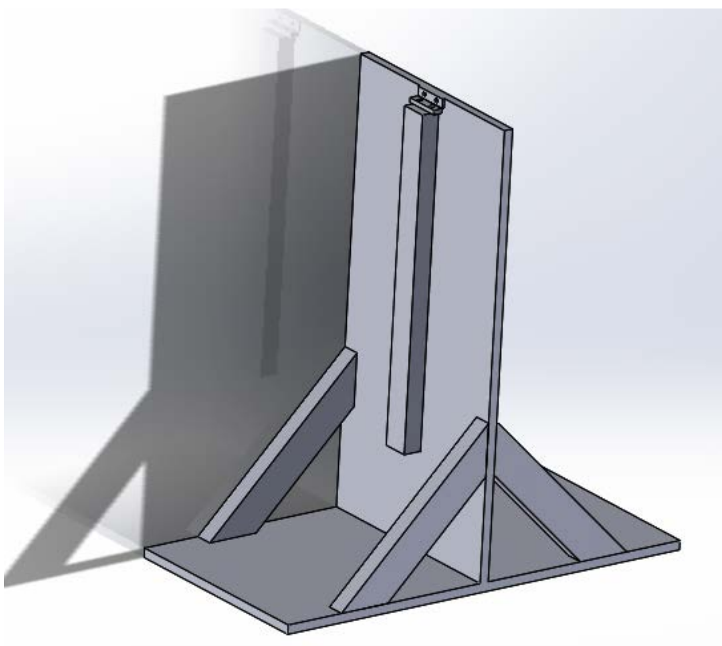

Figure 24: 3D Model of Helmet Testing Device

7.2 Design Changes

At the end of the last semester the team decided to create a testing device for the smart helmet project. The reason of that is because the team decided to test the transfer of data for the helmet. Another reason is the team thought about creating a system which works with any kind of helmet. As a result, the team decided at the beginning of this semester to start working on the testing device. The team faced many problems while working on the testing device. One of the main issues faced this semester is learning the coding process. Currently the team is working at the Arduino codes. In addition, the team selected one person responsible in attending the Arduino club meeting which will improve the performance of the team by understanding the concept behind working in the codes. This Arduino club improved the performance in working with codes by understanding the codes language and the sensor set up process as well.

Another problem the team faced was the transmission of data. The team is involved with two ways of transmitting data in smart helmet project. One way is getting a SD card, and the other is Bluetooth. The team faces many issues in figuring out the best process of transmitting data whether the SD card or the Bluetooth. The SD card is a way where the team transmit all the data in one small memory card. On the other hand, the Bluetooth is a way where the team can transmit data with a cell phone. At the middle of this semester, the team selected the Bluetooth process because the data can be transmitted faster than the SD card. Moreover, the Bluetooth does not lose data while the transmission process. However, the SD card could possibly lose some data during the transmission process. Thus, the team decided to work with the Bluetooth process in transmitting data with the smart helmet project. Also, the team will keep the SD card in case the Bluetooth process.

After deciding the process of transmitting data, the team worked with the testing device. This testing device should automatically hit the helmet without any human involvement. The reason is due to human error that might affect the accuracy of the data. The team chose the idea by using the American Society for Testing and Materials (ASTM) testing methods. The team finished the testing device at the middle of this semester. The ASTM helped the team understand the professional process of testing device in the engineering field. One of the problems faced while building the device is the angle of performance. The team should figure out the best angle of performance in the testing device. The team used the machine shop to create the testing device for the smart helmet project. The machine shop helped the team in having all the appropriate tools for construction.

Finally, the team performed the process of building the testing device in the machine shop. The team drilled the woods part together. The team used a hinge for the angle in the testing device. This specific piece helped the team in adjusting the angle of the testing device. Furthermore, the team faced a problem in adjusting the angle. However, the team figured out that the best performance of the angle in the testing device is 90 degree. The 90 degree have the best performance in the testing device because the team can control the initial and final position of the hit easily. Another reason of choosing 90 degree is this angle can go back and forth constantly. The team also wants to make sure to create the simple process in adjusting the angle and should be able to prove the basic concept of the project.

For now, there are no other implementation problems faced yet. For the future preference the team will update any kind of problem or any kind of process to the smart helmet project. The team did not test the helmet because some components are missing. For example, the gyroscope sensor did not arrive yet. The XBee shield V2.0 which is a part that connects the UNO board and the Bluetooth part. Therefore, the team will wait for any new update in the progress of the implementation in the smart helmet project.

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9 APPENDICES

9.1 Appendix A: House of Quality

Table A: House of Quality

Project: Smart Helmet
Date: 09/23/2018
Input areas are in yellow

	Decrease Impulse	Maintain volume	Increase factor of safety	Ductility	Increase power	Decrease diameter	Increase voltage
Decrease Impulse							
Maintain volume							
Increase factor of safety							
Ductility		(+)	(++)				
Increase power			(++)				
Decrease diameter		(++)					
Increase voltage			(+)		(++)		

Legend
- A Vicis
- B Ridell
- C xonano

Customer Needs	Customer Weights	Decrease Impulse	Maintain volume	Increase factor of safety	Ductility	Increase power	Decrease diameter	Increase voltage	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
		Technical Requirements							**Customer Opinion Survey**				
High protection	5	9	9	9	3	9					C	A	A
Similar size of helmet	4	3	9		3		9					B	AB
Life expectancy	4	9		9		9		3				C	A
More comfortable	3.5	9	3		9		3				A	A	
Transmit data	4.5	9	3			9							
Small sensor	3	9	3				9				BC	A	C
Strong battery	2					9		9			B		A
Technical Requirement Units		N.S	m^3	N/A	N/A	W	m	v					
Technical Requirement Targets		192	114	81	59	140	74	30					
Relative Weight %		27.9	17	12	8.5	20	11	4.4					
Rank order		1	3	4	6	2	5	7					

9.2 *Appendix B: Functional Model*

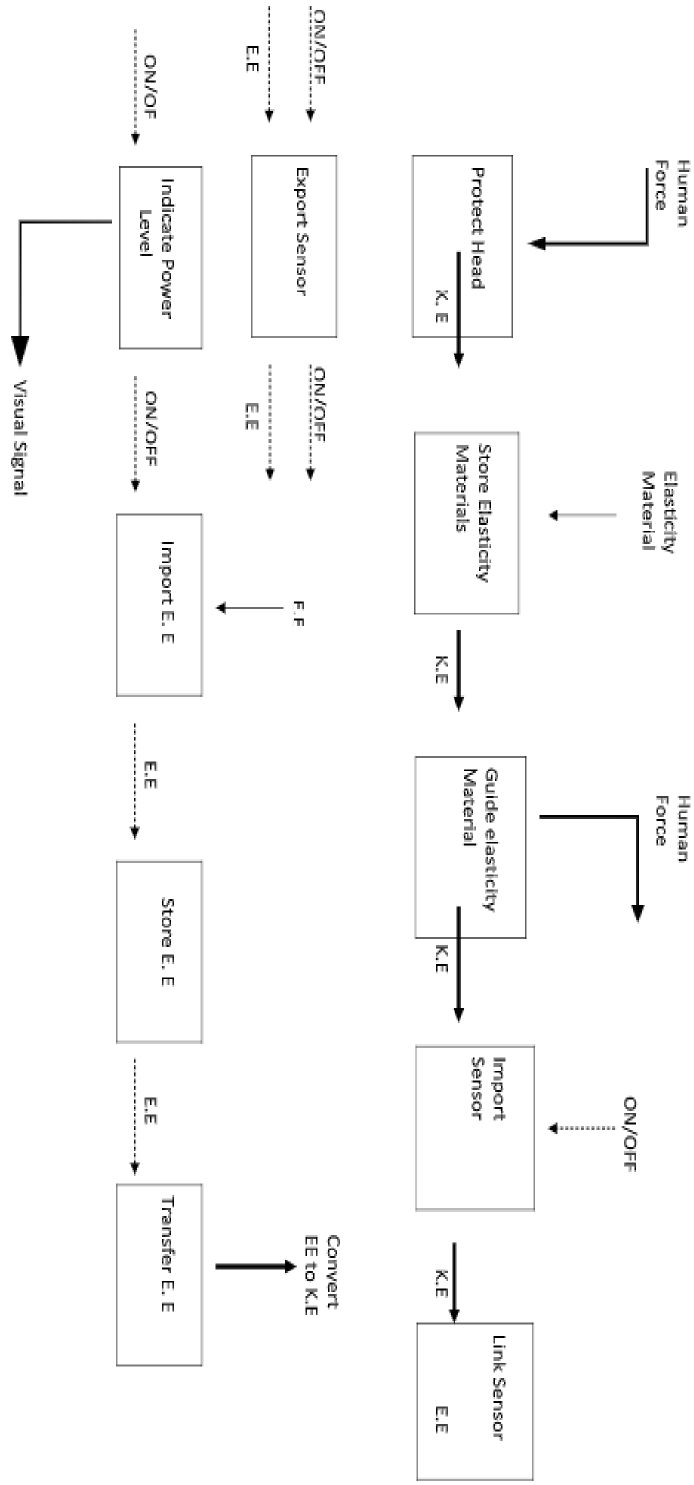
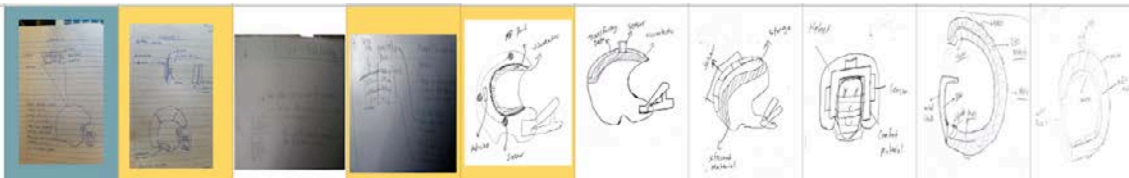


Figure B: Functional Model

9.3 Appendix C: Pugh Chart

Table C: Pugh Chart



Criteria	MR Fluid	Airbag	Transforming	Padding	MR Fluid #2	Transfering	Scupa Diving	Boxing helmet	D3O Helmet	Vibration
Light Weight	D	+	+	+	-	+	+	-	-	s
Affordable		+	s	s	-	+	-	s	+	-
Appearance	A	-	+	+	s	+	+	+	+	+
Safety		+	s	+	+	-	+	+	+	+
Controllability	T	+	-	s	+	-	-	-	-	-
Sensing		s	-	-	s	s	-	-	-	-
Data Collection	U	s	-	-	+	s	s	-	s	-
Sum (+)		4	2	3	3	3	3	2	3	2
Sum (-)	M	1	3	2	2	2	3	4	3	4
Sum (s)		2	2	2	3	2	1	1	1	1

9.4 Appendix D: Decision Matrix

Table D: Decision Matrix

		Design Options							
		Magnetorheological		Electrorheological		Viscoelastic		Airbag	
Criteria	Weight %	Score (1-100)	Weighted Score	Score (1-100)	Weighted Score	Score (1-100)	Weighted Score	Score (1-100)	Weighted Score
Light Weight	20	20	400	30	600	40	800	50	1000
Affordable	6	40	240	50	300	60	360	50	300
Appearance	5	80	400	80	400	90	450	75	375
Safety	30	90	2700	70	2100	60	1800	60	1800
Controllability	12	90	1080	70	840	10	120	60	720
Sensing	15	80	1200	75	1125	85	1275	80	1200
Data Collection	12	70	840	65	780	80	960	80	960
	100	Total	6860	Total	6145	Total	5765	Total	6355

9.5 Appendix E: Helmet CAD View

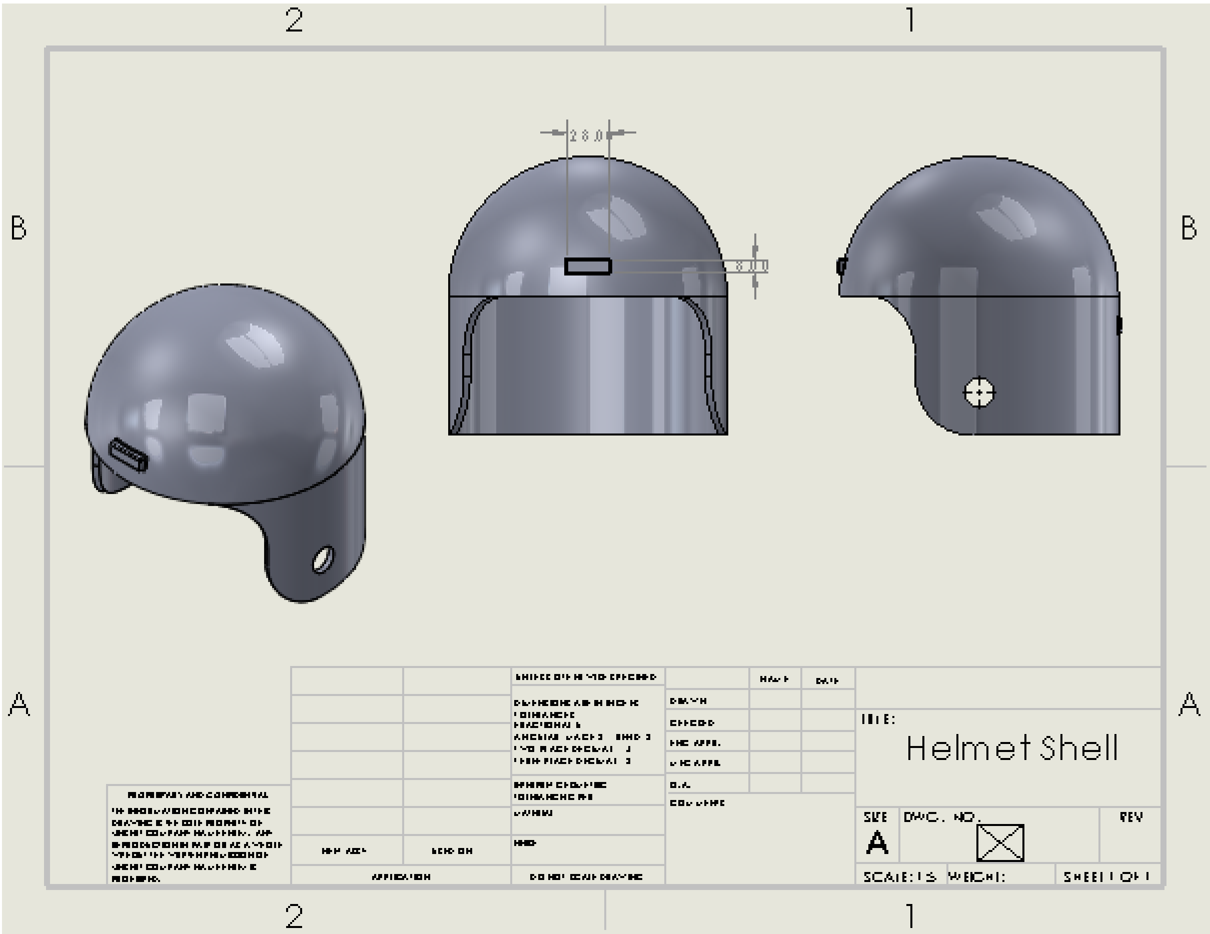


Figure E: Draft of Exploded View of Helmet

9.6 Appendix F: Inside of Helmet Padding CAD View

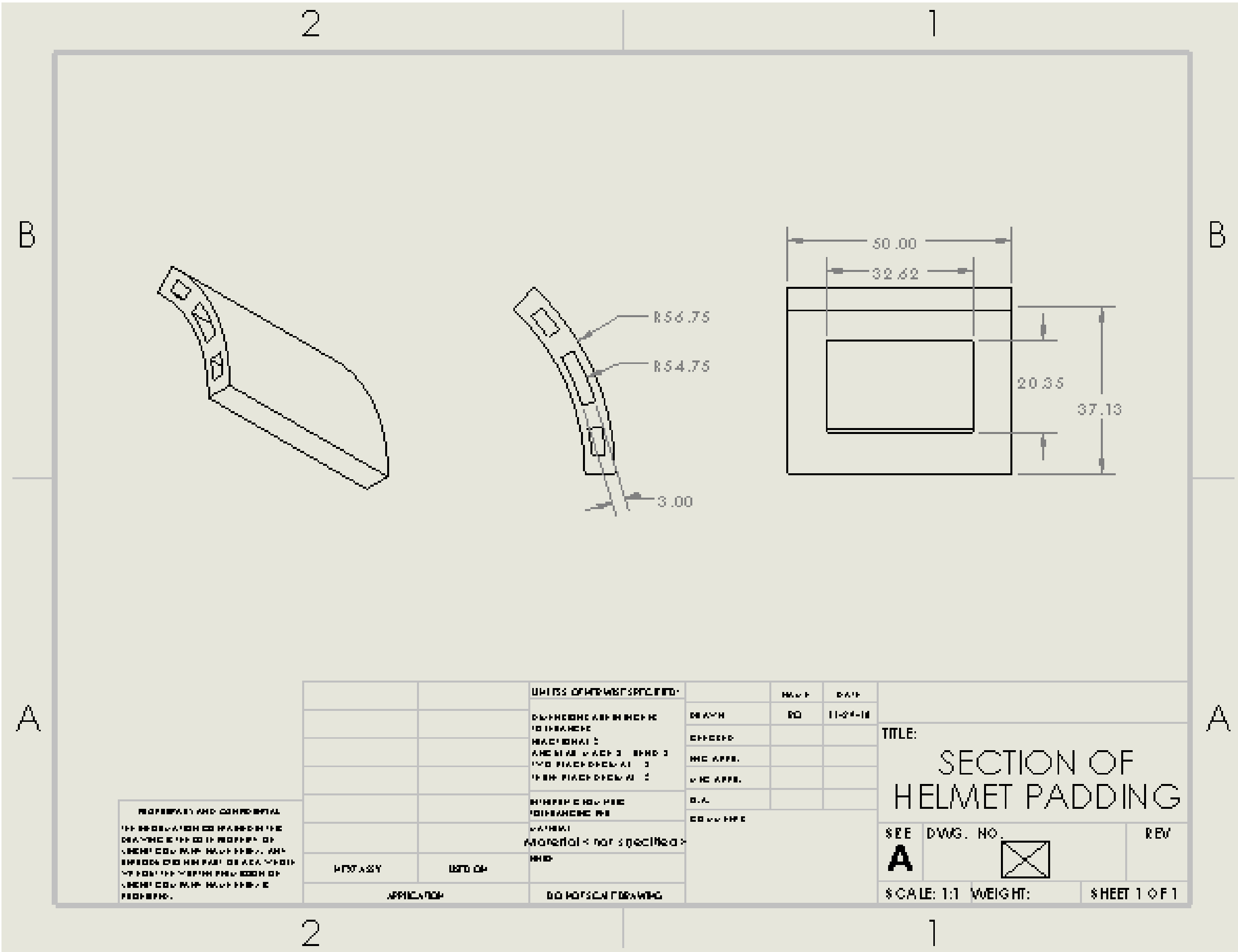


Figure F: Draft of Exploded View of Helmet Padding

9.7 Appendix G: Bill of Materials

Table G: Bill of Materials of our design (Smart Helmet)

Part #	Component Description	Quantity	Cost $	Ref.
1	Testing Helmet	1	19	[6]
2	D3O	2	127.6	[7],[8]
3	Laser Sensor Arduino	1	13.93	[9]
4	Laser Sensor VL53L0X	1	3.56	[10]
5	Data Memory	1	19.99	[11]
6	RTCSD-01	1	17.95	[12]
7	Bluno Bee (Bluetooth Arduino)	1	9.9	[13]
8	Triple-Axis Accelermeter 8g	1	7.95	[14]
9	Xbee Shield	1	9.9	[15]
10	Arduino Uno	1	19.99	[16]
11	Accelermeter 3- Axis sensor 200g	1	24.95	[17]
12	Triple- Axis Gyroscope	1	12.5	[18]
13	Mannequin Head	1	5.29	[19]
14	Arduino	1	60	[20]
		Total	352.51	

9.8 Appendix H: Schedule of ME 476C

Table H: Fall Gantt Chart

#	Task Name	Start	Finish	Assigned To	Duration
1	**Meeting 1**	09/11/18	09/12/18		1.146d
2	Client Meeting	09/11/18	09/11/18	M and R	40m
3	Team Chart	09/12/18	09/12/18		1h 10m
4	**Meeting 2**	09/17/18	09/19/18		2.281d
5	Shearing ideas	09/17/18	09/17/18		1h 15m
6	Staff meeting	09/17/18	09/17/18		1h
7	**Meeting 3**	09/19/18	09/19/18		0.281d
8	pre-presentaion	09/19/18	09/19/18	All	2h 15m
9	Meeting 4	09/23/18	09/24/18		2d
10	**review presentation**	09/23/18	09/23/18		1h
11	Presentation	09/24/18	09/24/18		1d
12	**Project Description**	09/24/18	09/24/18	Mana	1d
13	Background and Benchmarking	09/24/18	09/24/18	Race	1d
14	Design Requirement	09/24/18	09/24/18	Titus	1d
15	Customer needs	09/24/18	09/24/18	Omar	1d
16	Engineering Requirements	09/24/18	09/24/18	Omar	1d
17	Schedule and Budget	09/24/18	09/24/18	Fares	1d
18	Conclusion	09/24/18	09/24/18	Titus	1d
19	References	09/24/18	09/24/18	Titus	1d
20	Meeting 5	10/03/18	10/03/18		0.375d
21	**Website check**	10/03/18	10/03/18		3h
22	Meeting TA	10/08/18	10/08/18		0.125d
23	**Report**	10/08/18	10/08/18		1h
24	Staff Meeting 2	10/08/18	10/08/18		0.125d
25	**Giving the team parts to work on.**	10/08/18	10/08/18		1h
26	Staff Meeting 3	10/15/18	10/15/18		0.125d
27	Shearing the information of that parts with PhD	10/15/18	10/15/18		1h
28	Meeting 6	10/21/18	10/21/18		0.125d
29	pre-presentaion	10/21/18	10/21/18	all	1h
30	Presentation 2	10/22/18	10/22/18		1d
31	**Project Description**	10/22/18	10/22/18		1d
32	Designs Considered (Product)	10/22/18	10/22/18		1d
33	Design Selected	10/22/18	10/22/18		1d
34	Schedule & Budget	10/22/18	10/22/18		1d
35	Staff team meeting 4	10/29/18	10/29/18		1d
36	**Meeting with professor/ Website check 2**	10/29/18	10/29/18	All	1d
37	Meeting 7	10/31/18	10/31/18		0.125d
38	**Website check 2**	10/31/18	10/31/18	All	1h
39	Staff team meeting 5	11/05/18	11/09/18		5d
40	**Analytical Reports due**	11/05/18	11/09/18	All	5d
41	Meeting 8	11/14/18	11/14/18		0.125d
42	**Discussing next assignments**	11/14/18	11/14/18	All	1h
43	Staff team meeting 5	11/19/18	11/19/18		0.042d
44	**Discussing the update of the team' parts**	11/19/18	11/19/18	All	20m
45	Meeting 9	11/20/18	11/20/18		0.125d
46	**review presentation**	11/20/18	11/20/18	All	1h

	Task Name	Start	Finish	Assigned To	Duration
47	Presentation 3 final	11/26/18	11/26/18		**1d**
48	**Project Description**	11/26/18	11/26/18		**1d**
49	Designs Considered (Product)	11/26/18	11/26/18		**1d**
50	Design Selected	11/26/18	11/26/18		**1d**
51	Schedule & Budget	11/26/18	11/26/18		**1d**
52	Meeting 10	11/28/18	11/28/18		**0.125d**
53	**Discussing the final report and dividing the work**	11/28/18	11/28/18	All	**1h**
54	Staff team meeting 6	12/03/18	12/07/18		**5d**
55	**Discussing Full prototype**	12/03/18	12/03/18		**1d**
56	BOM, & CAD package, Full prototype	12/03/18	12/07/18		**5d**
57	Website check 3	12/03/18	12/07/18		**5d**

9.9 Appendix I: Schedule of ME 486C

Table I: Spring's Current Schedule

Task Name	Start	Finish	Assigned To	Duration
Plan of Spring 19	01/20/19	03/01/19		31d
Website check 1	01/20/19	02/01/19		11d
Hardware review 1	02/18/19	02/22/19	All	5d
Indv. Analysis	02/26/19	03/01/19	All	4d
Midpoint Presentation	03/08/19	03/12/19	All	3d
Hardware review 2	03/29/19	03/29/19		1d
Midpoint report	03/05/19	03/08/19	All	4d
Website check 2	03/29/19	03/29/19		1d
Final product testing proof	04/12/19	04/12/19		1d
UGRADS practice	03/10/19	03/10/19		1d
Operation Manual and Assembly	04/26/19	04/26/19		1d
UGRADS	04/23/19	04/23/19		1d
CAD Package	05/03/19	05/03/19		1d
Final Report	05/03/19	05/03/19		1d
Website Final Check	05/07/19	05/07/19		1d
Staff meeting 19	01/24/19	02/28/19		25.042d
Staff meeting 1	01/24/19	01/24/19		20m
Staff meeting 2	01/31/19	01/31/19		20m
Staff meeting 3	02/07/19	02/07/19		20m
Staff meeting 4	02/14/19	02/14/19		20m
Staff meeting 5	02/28/19	02/28/19		20m
Staff meeting 6 (Team meeting)	02/28/19	02/28/19		20m
Staff meeting 7	03/07/19	03/07/19		20m
Group Meeting 19	01/22/19	01/29/19		5.156d
Team Meeting 1	01/22/19	01/22/19		1h
Team Meeting 2	01/29/19	01/29/19		1h 15m
Team Meeting 3	02/10/19	02/10/19		1h 30m
Team Meeting 4	02/12/19	02/12/19		2h
Team Meeting 5	02/17/19	02/17/19		1h 20m
Team Meeting 6	02/28/19	02/28/19		2h
Team Meeting 7	03/05/19	03/05/19		1h 30m