Measured Accumulative Underlying Real-time ImpaCt Endo-skeleton "MAURICE"

ECE4011 Senior Design Project

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NEWTONIAN/MAURICE

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Executive Summary

The main goal of our project is to design a tactile, mobile health monitor to be worn by football players at both college and professional levels. The motivation for designing such a product comes from the current issue revolving around repeated concussions, which increase players risk with health issues. This technology will notify the medical staff, not only that a player was injured, but also where they were hurt on the previous play. Despite precaution, players are sometimes moved hastily, causing further injury to the player as he may have not been able to indicate what bone or muscle was damaged. This suit will reduce the medical staff's dependence on the coherence of the player by using several sensors to monitor different parts of the body including, measuring the force of impact received by the player. The additional parts that we add to the player's uniform will monitor the most vital parts of the body, including the head/neck, lower back, and shoulder areas, and will constantly measure the force of impact caused during each collision in which the player is involved. If a collision registers a force in Newtons that is beyond what is safe, an alert will be sent to coaches and staff on the sideline, bringing attention to the afflicted player. Our product has the potential to identify concussions and serious injuries as soon as they appear, allowing coaches to step in and prevent further damage to their players. The hardware included in the design will be a Raspberry Pi 3 Model B which will collect the data obtained from the sensors and will transmit that data to the cloud. The Amazon Web Services Simple Queue Service (AWS SQS) will be implemented on the backend in a first-in-first-out priority. A front-end application will be developed that takes this information and displays it in a GUI that the coaching staff will be able view the data immediately. The estimated cost of the parts used is $212.72, with the most expensive item being the load sensors, as well as the cloud services being provided by Amazon monthly. The cost of labor per unit is $283.01. The proposed selling cost will be $800 per unit.

Measured Accumulative Underlying Real-time Impact Endo-skeleton

1. Introduction

The football community has a dire problem that has beleaguered it since its inception in 1869. The human body sustains permanent damage from participation in the sport, and there are no organizations that have used modern technology to make the sport as safe as possible for the players. To remedy this issue, our senior design team (Team Newtonian) has begun designing a full body suit to detect heavy collisions that may result in concussion or serious injury. We have titled our product M.A.U.R.I.C.E (Measured Accumulative Underlying Real-Time Impact Endo-Skeleton). Maurice will be a proof of concept product that will transform already existing padding made by companies such as Riddell and Schutt, and transform them into data hubs capable of recording every hit that a player withstands during a game. This data will be sent to an application where coaches can view and analyze the data, making prompt decisions on the health of each player on the team.

1.1. <u>Objective</u>

The overall objective of this project is to provide coaches and training staff with quantitative data on the current health of their players on the field by recording the amount of force a player has withstood over the duration of the game. Rather than keeping track of the entire athlete's body as a whole, our design will only monitor the most vital areas, namely the lower back, and neck area. The data obtained will then be sent to the coaching staff via an application for immediate feedback. The project is a portion of a much larger design in which the ideal scenario would be to eventually develop a product that is able to monitor a majority of a player's body and provide a wider range of medical data, such as heartrate, attained speed, precision of routes, etc.

1.2. Motivation

The motivation behind this project is the immediate health, as well as the long-term quality of life that students go on to live after football. While concussions have been at the forefront of the debate on player safety, the general effects of the game overall on the body is largely overlooked. The extensive amount of pain that players sustain has largely been blamed on the epidemic of painkiller abuse among professionals and students alike. Earlier this year in an interview with Fox News, former Ohio State University football player Shane Olivea revealed that at one point he was taking over a hundred Vicodin pills a day, Furthermore, the National Football League (NFL) has been accused of handing out pain pills like candy. Initially, this product will be intended for college athletes who, unlike professionals, are not payed for their sacrifices on the field. Currently, there are no products in use at any level that provides the functionality that we look to provide in our product. Companies such as Riddell have dedicated funds to technology for changes in the materials being used in the padding and helmets, however, as of yet there are no products that are used by the NCAA or NFL that delivers data on the health of a player's entire body in an application. Our product will not be launched as a cost-effective product, but as a life effective product. Currently, the NFL only carries former players on their corporate health insurance plan for up to five years after a player has retired, and this does not apply to players who were in the NFL for less than three years. Considering the average player's career only lasts for 3.9 years, there are many who will never qualify for the NFL's retirement coverage altogether. Colleges do not offer additional insurance beyond the student's eligibility at all. This is problematic for any participant in the sport as the effects of back and knee injuries can linger long beyond the grace period.

1.3. Background

Key building blocks to ensuring the success of this project will lie in the transmission of recorded data from the sensors to the application. Not only does this transmission have to complete, but it must do so within the time the average college football play lasts, which is 6.07 seconds. The reason behind this number is that it is imperative that the training staffs are aware of the player's injuries before they attempt to assist him off the field, lest they risk causing additional damage by improperly handling an injured player.

In recent years, Riddell has partnered with the Virginia Institute of Technology to improve the design of their helmets and padding, reducing the number of concussions using their Riddell Flex helmet. However, Riddell has not pushed products with sensors that are built into the padding to the NCAA or NFL, largely due to the significant cost that it would impose as well as the reduction of mobility. This same issue will be something that will be challenging for our product. Our MAURICE system will include the following features:

2. Project Description and Goals

The goal of this product is to increase player safety and longevity by providing real-time data on the force withstood over the course of a football game. To accomplish this, a Raspberry Pi 3 will be used to control the sensors and obtain the data. The pi will then access the IP address of a cloud server where the data will be stored. The application will then download and refresh its data from the cloud and use this data to display information to the user.

Product Features:

- Database of player health
- Sensors measuring force withstood

- Application that displays visuals of data
- Cloud Storage
- Animated 2D skeleton with color coded injury diagnosis

The monitoring process begins at the sensors which record the force withstood based on measurements taken by an accelerometer and gyroscope. These sensors will feed their data into a Raspberry Pi 3, which will send the raw data to a cloud server, identifying the player that the data belongs to and subsequently storing it in the player's profile on the server. From this point, the front end of the application will process the data and convert it into a visual of the human body where fatigue and injury are indicated by a color-coded system in which severely stressed, and possibly injured portions of the body are shown in a dark, crimson hue. The core of the product will lie in the database which will hold the data on each individual player. This information will be pulled down from a cloud server, taking account pre-existing injuries, personal statistics such as height and weight, and the number of plays participated in. Despite the challenges, a basic, working prototype is the goal with the above functionality being the baseline. The tablets that will be used to run the application will not have access to the internet like the Surface Pro's that the NFL uses on the sidelines. Instead, a mobile phone will be used as a hotspot, broadcasting internet throughout the testing site.

3. Technical Specifications

The proposed product is required to seamlessly communicate between the on-body device and the user-interfaced endpoint on milli-seconds time scale, for approximately 150 MAURICE units. Within this time-span, sensory data that is periodically collected by the dedicated microcontroller is sent to the cloud services for processing and storing, and pushed to the user’s web-app for analytics display. The system will consist of an accelerometer, optical heart rate, force sensitive resistor to collect impact and force data. The prototyped system will also consist of a Raspberry Pi 3 Model B, an internet capable computer device (Laptop and/or tablet), and a suite of Amazon Web Services.

3.1. Raspberry Pi 3 Model B

Processor	• Quad Core 1.2GHz Broadcom BCM2837 64bit CPU
Memory	• 1GB RAM
Connectivity	• BCM43438 wireless LAN and Bluetooth Low Energy (BLE) on board
Storage	• Micro SD port for loading your operating system and storing data • Up to 16GB External SD storage
Ports and Pins	• 40-pin extended GPIO • 4 USB 2 ports • 4 Pole stereo output and composite video port • Full size HDMI • CSI camera port for connecting a Raspberry Pi camera • DSI display port for connecting a Raspberry Pi touchscreen display
Power	• Micro USB power supply (2.1A)

3.2. Concussion detection sensor (Accelerometer)

Acceleration (G Force)	• 0 to 200 Gs (1g = 9.8 m/s)
Sensitivity	• 98 mg/digit @ (+-200 g)
Operating Temperature	• +85 ˚C Max

3.3. Impact Detection (Load Cell)

Force	• 0 to 200 Kg

Sensitivity	• 76 mg/digit @ (+-200 Kg)
Operating Temperature Range	• -20 to 60 ˚C

3.4. Pressure detection (Flexi-Force sensor)

Maximum Force	• 445 N (100 lbs)
Sensing Area	• 9.53 mm
Response Time	• < 5 µsec

3.5. Heart Rate detection

Range Pulse	• 0 to 200 bpm
Max. Sampling Rate	• 100 samples/sec
Range Waveform	• 0 to 5 V

3.6. Cloud

Queue	• AWS Simple Queue Service (FIFO)
Server	• AWS Lambda • AWS Elastic Compute Cloud
Database	• DynamoDB (NoSQL) database

3.7. Dashboard (Web-app)

Frontend Language(s)	• HTML/CSS • JavaScript

Backend Languages(s)	• Python • C#
Framework	• Flask (Python)

4. Design Approach and Details

4.1. Design Approach

4.1.1. System Overview

There are three main components to MAURICE: the hardware within the suit, the cloud, and the web application. Figure 1. shows the block diagram of the overall system.

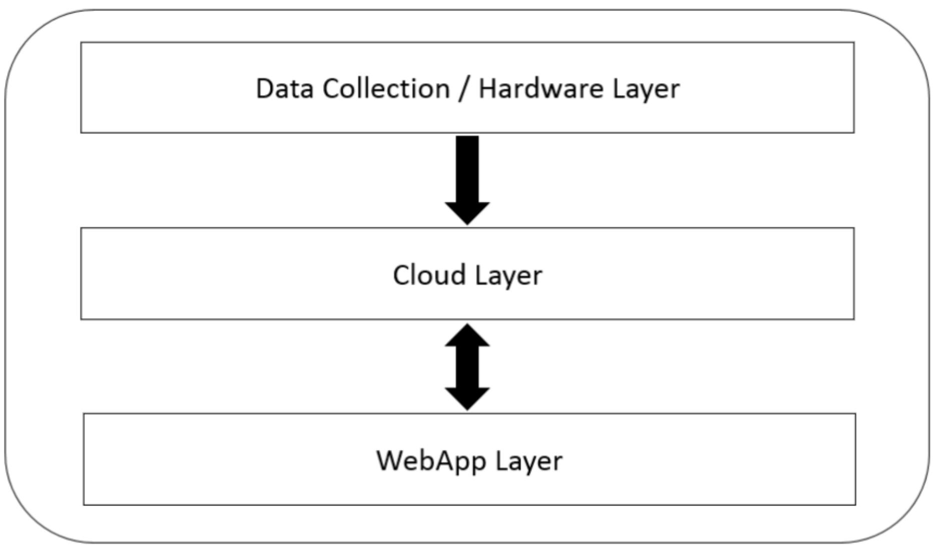

Figure 1. A block diagram of the MAURICE system

The hardware side consists of sensors, a microcontroller, and a battery. The microcontroller receives the measured data from the sensors and transmits them to the cloud layer through its Wi-Fi chip. The Cloud layer processes the received data from the hardware side; it stores the data into the data base, regressively analyzes the data, and transmits to the web application server. Lastly, the web application is an intelligent Graphical User Interface (GUI), which represents the health status of the player wearing the corresponding suit by 2-D image of a human body, graphs, and color scales.

4.1.2. Hardware

The hardware layer mainly includes sensors, which are embedded into the corresponding parts of the suit and a microcontroller and a power source located at the back of the suit. Figure 2. Illustrates communication and data flow between each hardware device.

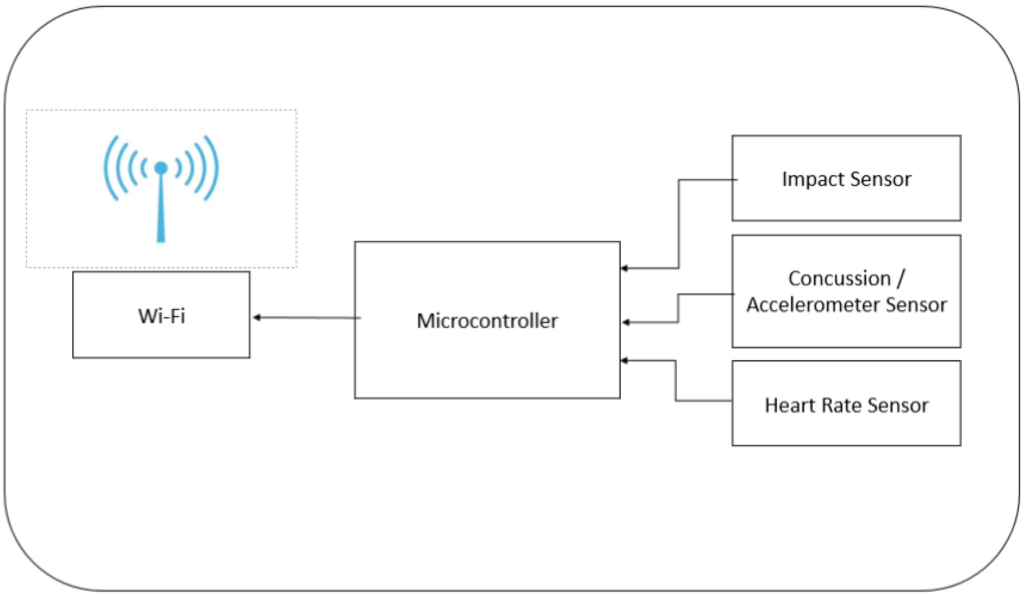

Figure 2. A block diagram of the hardware communicating system.

4.1.2.1. Sensors

There are three types of sensors that are going incorporated into the suit; an impact sensor, concussion sensor, and heartbeat sensor. The impact sensor is a semi-conductor device, which changes its resistance corresponding to the magnitude of exerted impact [1]. It will measure the magnitude of impact a body part experiences in terms of voltage and current. The concussion sensor will be specifically added to the player's helmet; it is essentially an accelerometer, which measures the shock exerted to the helmet in terms of an acceleration. Studies show mild concussions begin to occur approximately at 100g of exerted force on a player's head and severe concussions at about 150g. The sensor implemented on the helmet should be capable of measuring above this threshold [2]. Finally, there is a heartrate sensor, that measures pulse based on optical power variation as light is scattered during its' path through the blood as the blood flow changes during a heart cycle [3].

4.1.2.2. Microcontroller

The measured data from the sensors will be collected by a Raspberry Pi. The Raspberry Pi is a small, single board computer that includes a variety of features such as GPIO, networking, and a real-time clock. Its function is to receive measured data from the sensors and transmit it to a cloud server using a built in Wi-Fi module [4]. The Raspberry Pi can do a lot more in terms of computation than what is needed for this project. Despite this, we are using it for our prototype since it is a proven controller that can handle this task with limited complications and increased simplicity. If MAURICE were to be used in a typical application i.e. needing mass manufacturing, then a low-cost microcontroller would be used. The PCB board including the microcontroller, and a power supply will be mounted on the back of the player's suit. It will transmit real time sensor data at a certain sampling frequency based on the logic of the interrupt-based programming. This rule will be applied to not only the microcontroller, but also the cloud and web application layers to operate the entire system in real-time.

4.1.3. Cloud

The concept behind Cloud computing is using a network of remote servers hosted on the internet to store, manage, and process data, rather than a local server or a personal computer. Nowadays, cloud computing does not only provide web-based storage, but also variety of applications to users [5]. The key role of the cloud layer is to process data received from the other layers, update it into the data base, and transmit the processed data to the GUI app. Figure 3. demonstrates the data processing mechanism in the cloud service layer.

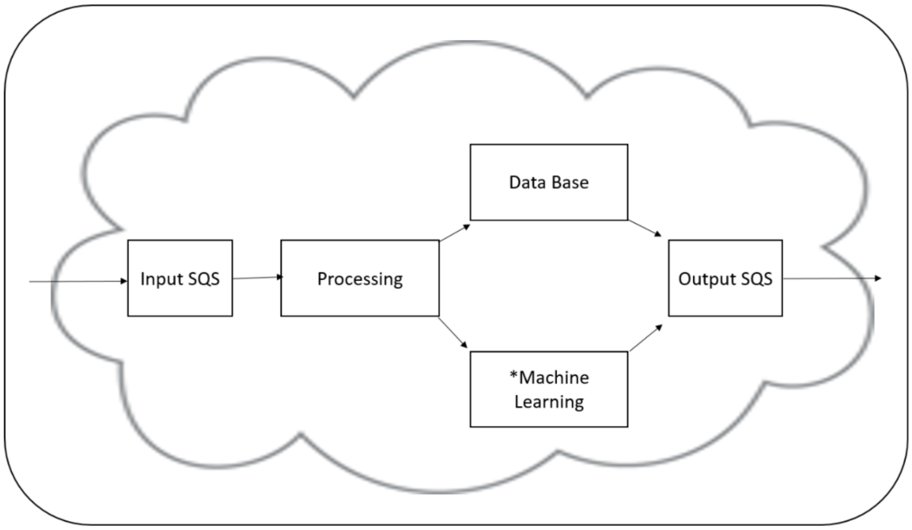

Figure 3. Block diagram of the cloud layer showing the processing and storage of data. (* Possible expansion component)

4.1.3.1. Communication Layer

The cloud server communicates with other layers by receiving and transmitting data through its' input and output queuing services – the Aws Simple Queue Service (SQS), as a First-In-First-Out (FIFO) structure. The input queue collects the received sensor data from the microcontroller in each player's suit to be processed. The cloud services handles transmitting, processing, storing, and receiving data between the sensors and the web application servers. The web application interface requests the processed data to be rendered on the GUI layer.

4.1.3.2. Data Processing

The data received from other layers will be stored into the data base existing in the cloud server. Request signal data from the web application layer will be used to determine when to transmit the collected data from the microcontroller while the received data from the microcontrollers will be transmitted to the web application layer after it is stored into the data base. The data collected from the microcontrollers also will be regressively analyzed based on the machine learning algorithm to transmit the analytical data to the GUI layer, but it might not be included in our final design based on the computational calculation cost and the change of time.

4.1.4. Graphical User Interface

The GUI layer collects the data of each player from the cloud layer and represents it visually by using a 2D image of a human body, graphs, and numerical values. Figure 4. illustrates a view of a single player and his or her data on the GUI.

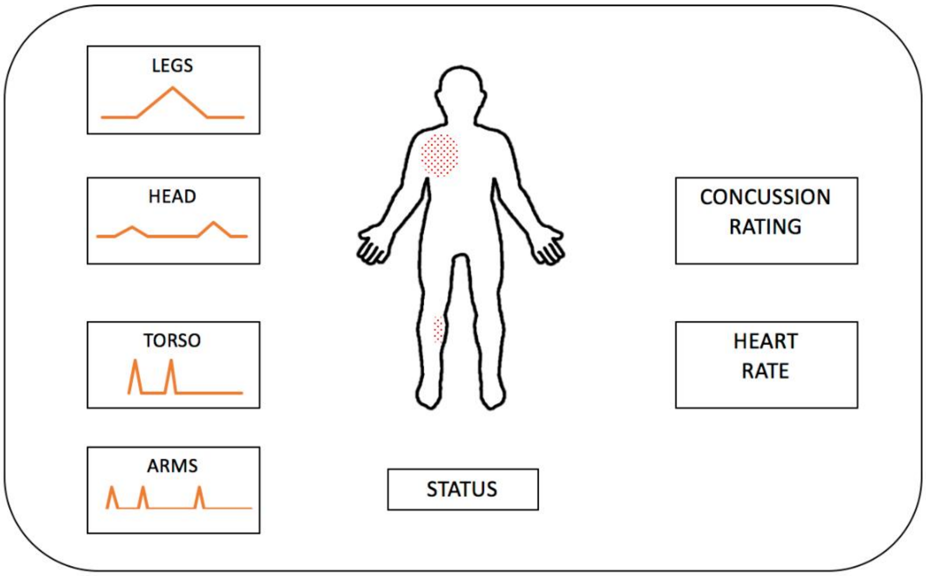

Figure 4. The proposed GUI interface to represent the processed data

The left side of the screen contains live graphs showing real time impact data of the legs, head, torso, and arms measured by impact sensors attached to the suit. The right side of the screen displays a graph representing the measured heartrate of the player, a number corresponding to the concussion(acceleration) rate and an associated safety scale. While the impact and heart rate graphs represent the measured sensor values over time, the concussion rate is determined by the accumulated concussion sensor values over time. The 2D image of a human body located at the center of screen illustrates the degree of injury of each body part by color. A player's body condition at the beginning of the match is represented by the color blue, and the corresponding body part becomes a darker shade of red as more damage is accumulated on a specific part of the body as the match progresses. The health status of the player is determined by the overall injury rate of the player's body, and it will be in the box below the 2D rendering of the human body as text.

4.2. Codes and Standards

The handling of data pertaining to an individual is characterized as personal and sensitive. When collecting this data from a user that wears a MAURICE suit, the data is required to follow the NIST800-53 (Technical Access Control) data security standards. In abiding to the NIST800-53 standards, the transmission, storage, accessibility, active account management and role authorizations must be established. The transmission of data that is deemed personal should follow the Technical Access Control AC-1 Access Control Policy and Procedures P1 [6]. More notably, the data that is to be collected relates to the user's health information that demands maintaining government controlled standards in the acquisition, transmission, storage, and manipulation of collected data [7]. The collected data that is to be transmitted will be sent over a secure and encrypted wireless communication network, that uses a *Private-Public key hashing* technique to validate data. Making use of Amazon Web Services solutions, the security of the data is in-built into the services, with the User Roles methodology. On the consumption side of the data, User-Password authentication will be used to ensure authorized access to sensitive data.

Since we will be relying on Wi-Fi communication to connect the data collection points i.e. the smart suit to the cloud we will need to follow a widely used Wi-Fi standard. IEEE 802.11 is a wireless-networking standard that uses multiple antennas to increase data rates [8]. Almost every Wi-Fi access point today is compatible with this standard. We need to use hardware that would also follow this standard on our suit like the Raspberry Pi single board computer.

4.3. Constraints, Alternatives, and Tradeoffs

4.3.1. Durability

We intend to subject our product to high force impacts from all angles. All sensors and measuring devices will need to be able to operate under these conditions without sacrificing the integrity of their readings. Approaching this problem, our team has considered using padding to lower the probability of damage to these devices.

4.3.2. Power Consumption

MAURICE is composed of different electronic components that will be frequently polled to detect collisions that exceed a certain threshold. Since MAURICE will be located on the body of its wearer, a long lasting, portable power source capable of providing of enough voltage to all our devices. The intent is for this power source will be rechargeable.

4.3.2 Size

The microcontroller used to gather data before sending it to the cloud will have to be placed in such a that it does not interfere with player mobility. The Raspberry Pi 3 is decently size, so our team will need to assess our prototype installation of MAURICE to determine the best position.

5. Schedule, Tasks, and Milestones

To guide the group in setting milestones and managing our time, the group created a detailed time line to describe the estimated time for each task our project requires. As discussed during lecture, a GANTT chart is used to outline and schedule all tasks needed for this project from beginning to end (Appendix). The GANTT chart estimates the duration of each task based its difficulty. Each task is assigned to the team member(s) most suited to complete it, except for the website, which everyone will contribute to. For example, the Prototype Component Board (PCD) assembly and design task will be taken by the team members majoring in Electrical Engineering or Computer Engineering with a hardware focus, while the GUI implementation and backend design will be assigned by those who specialize in software. The more time-consuming processes are expanded upon in the PERT chart. This chart breaks down sub tasks comprising the critical path tasks. To minimize the risk of spending more time then we have allotted on these tasks, our group is prepared to "borrow" members from our internal teams who have experience on the tasks to expedite the process.

6. Project Demonstration

The system will be designed to fit an average male athlete and will take place on an athletic field. Testing will not be conducted on a test subject due to possible injury. The demonstration will consist of the following:

1. The tester will stimulate different sensors on the MAURICE system.
2. MAURICE will measure the force of the impact.
3. MAURICE will relay information to the cloud database.
4. An internet capable device will display live information from the cloud database.

This process will be repeated as needed to highlight impact detection, as well as MAURICE's capabilities of assessing compound impacts to specific body parts. Other demonstrations will be performed to test specific aspects of the system hardware.

6.1. Impact Measurement

The first demonstration will have the system mounted in a fixed position, and the tester will proceed to hit the system with an object. The objects will vary every test in order to simulate two body parts colliding at different forces. The GUI will display the results and present the accuracy of impact data.

6.2. Heart Rate

For this demonstration, the heart rate sensor will be placed on the finger, and the displayed results will track the individual as he or she goes from rest to an active state. The tester and the data will be monitored simultaneously to check for the speed of the transmitting data and the latency of the GUI.

6.3. Acceleration

To test the accelerometer, the helmet will be suspended from a rope, and the tester will proceed to push the object in forward motion. The tester will progress to hitting the helmet with an object to simulate an impact. The values represented on the GUI will change depending on the amount of time the helmet accelerates and how quickly the helmet accelerates.

7. Marketing and Cost Analysis

7.1. Marketing Analysis

Concussions have been a topic of great concern in football, and this has motivated a demand for advancements in technology that prevent these injuries. There currently exist multiple products that track impacts to the head and relay the information to a mobile application. Of these products, two particular products stand out – *Riddell InSite* and *Shockbox*. Taking a closer look into the aforementioned products:

Riddel InSite:

The Riddell Insite system is composed of sensors positioned inside player helmets to monitor impacts received during play, while computing the metrics associated with said impact (e.g. location, linear and rotational acceleration). High magnitude impact sends a detailed alert to coaches, detailing the impact and player information [2]. The Insite system sells for $1000, and includes software to track each player registered in its database [3].

Shockbox:

Shockbox Helmet Sensors offer a portable sensor that can be placed on athletic helmets, as opposed to sensors that are embedded in the internal padding of a helmet. Each sensor interfaces with a mobile phone application through Bluetooth communication, sending alerts when a sensor detects an impact over its set threshold.

Our product has multiple capabilities including those from both products: integrated suit sensors, website, mobile application, and cloud services. These products exist as external attachments to a sports' helmet while our technology is embedded within players' equipment. This allows for more accurate measurements. More notably, these products have little to no focus on other parts of the body. The MAURICE system tracks the head, limbs, and the chest area allowing for a larger number of measurement points and better critical decisions made by the application.

7.2 Cost Analysis

7.1.1. Cost of Components

Raspberry Pi 3	$ 39.95
Sensor – Heart rate/pulse	$ 24.99
Sensor – Accelerometer (H3LIS331DLTR)	$ 9.95
Sensor – Load cell	$56.95
Sensor – Flexi force Sensor	$ 19.95
ADC for Pulse Sensor and Flexi Force Sensor	$ 14.99
Amplifier w/ ADC for Load cell	9.95
Power source – External battery pack	$ 35.99
Total Component Costs	**$212.72**

7.1.2 Cost of Labor (R &D)

Team members	6
Engineering Salary per person	$ 60,000 /year or $ 5000 /month
Project timeline	5 months
Total labor cost	***$150,000.00***

7.1.3 Cost of Production

MAURICE unit	$ 212.72
Estimated units sold (10 NFL teams of 53 players each)	530 units
Cost of labor for each unit (Labor cost for 5 months ÷ Number of units)	$ 283.01
Total production cost	**$495.7 / unit**

7.1.4 Profitability

Projected Sales	530 Units
Selling Price	$800 / unit
Profit per unit (Selling price – Cost of Production)	$ 304.3
Total Profit for 5 months	**$161,279.00**

7.1.5 Maintenance Costs (to the customer)

Cloud Service (10 or less concurrent users): • Web Servers X 3 – (2 Cores, 8GB RAM, 500 GB HDD) • App Servers X 2 – (4 Virtual Cores, 16 GB RAM, 30 GB HDD, 15 GB Data transfer)	$ 63.15 (per month, per NLF team)

8. Current Status

As of January 19th, 2018, our team has begun the process of ordering parts for our prototype. Currently, we are in possession of a Raspberry Pi 3 Model B to use as our microcontroller. In the coming weeks, we hope to receive the funds to purchase all components needed (*See Cost Analysis*). The hardware sub-team also plans to acquire all components to be sent to an external company for fabrication onto a PCB. Over the next couple of weeks, we will come together to start our first task, which is the website detailing our project.

9. References

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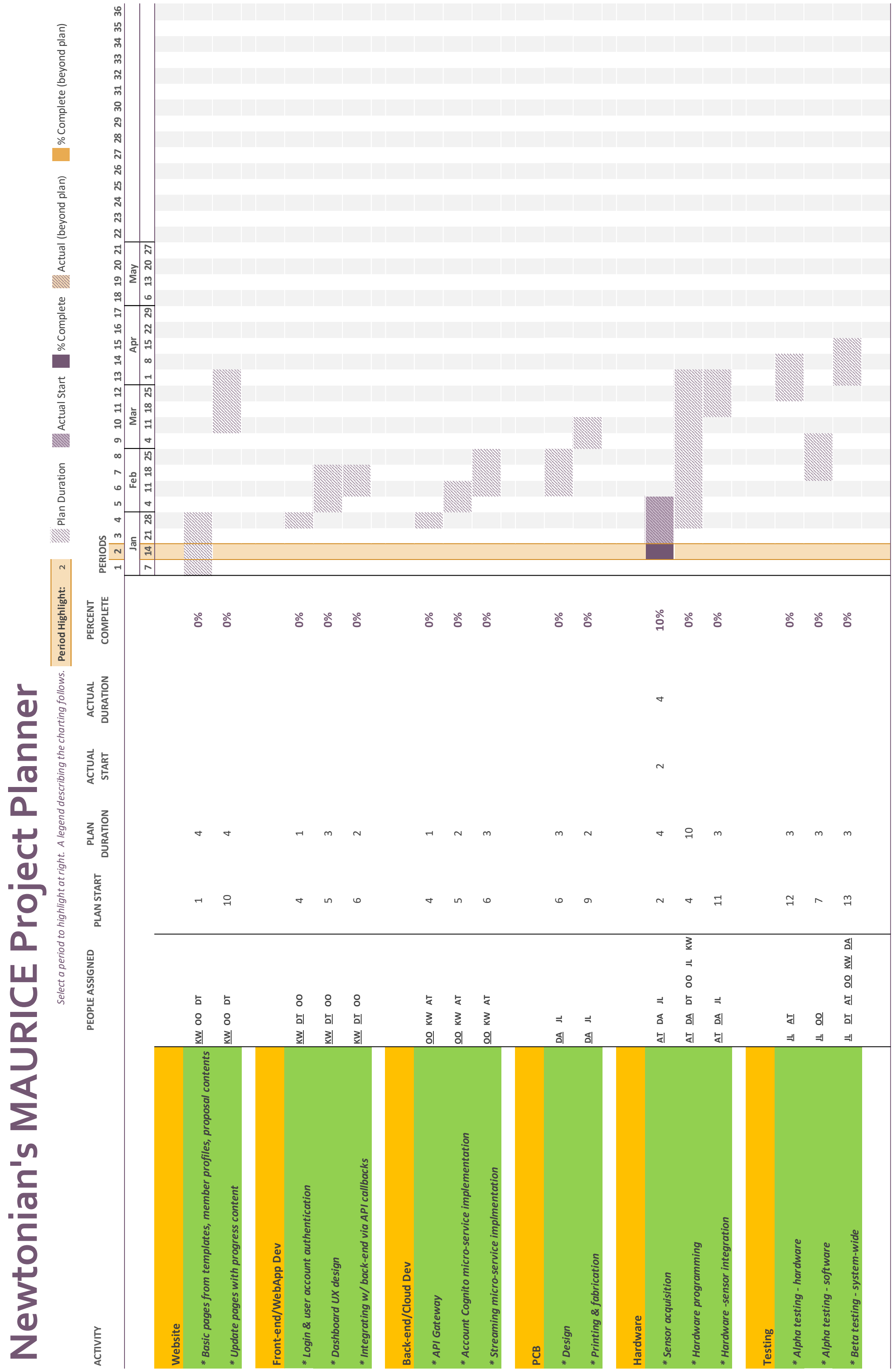
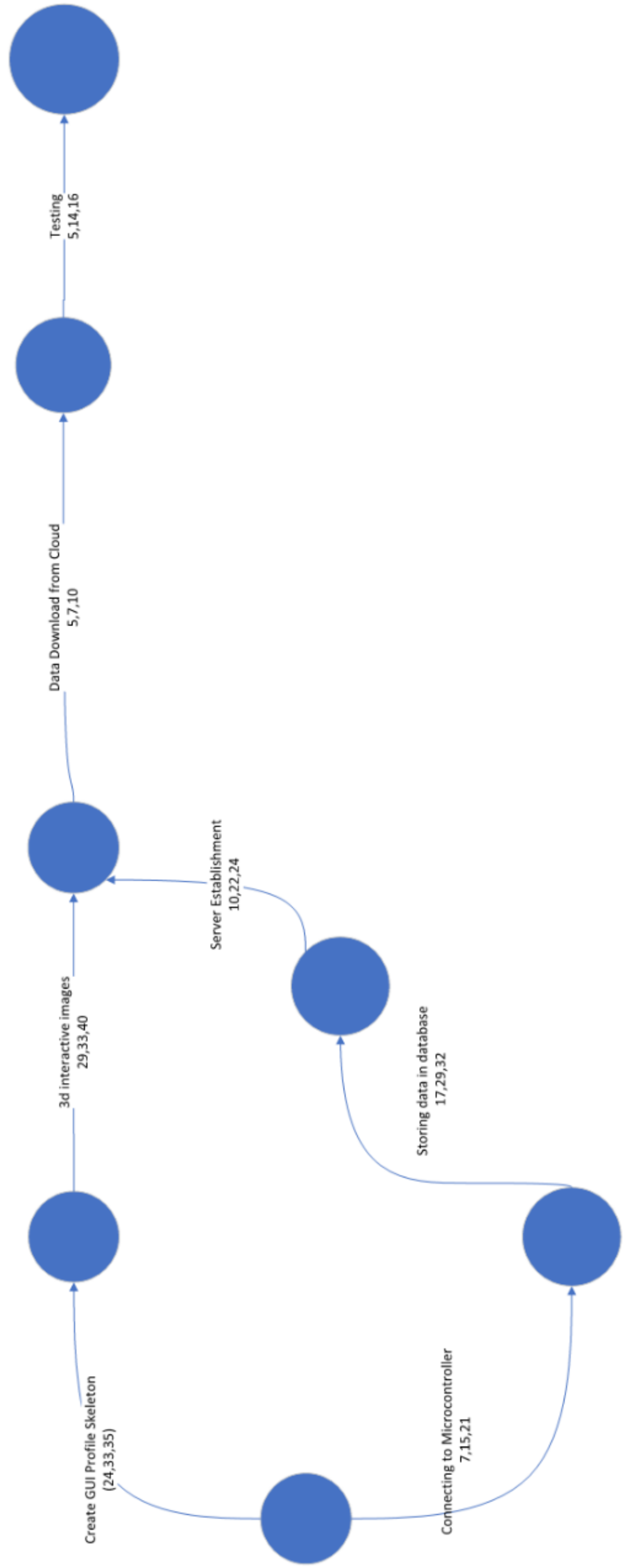
Appendix

A. GANTT Chart



Team-Member	***Initials***	***Team(s) Led***	***Other Obligation(s)***
Aaron Thurston	**AT**	Hardware	Back-end
			Hardware
			Testing
Daniel Albuquerque	**DA**	PCB	Website
		Hardware	Testing
Dre Taylor	**DT**	Front-end	Website
		Weekly Summary	Testing
Jiwon Lee	**JL**	Testing	PCB
			Hardware
Kevin Webb	**KW**	Website	Back-end
		Front-end	Testing
		Design Book check	
Olatide Omojaro	**OO**	Back-end	Website
			Front-end
			Hardware

B. PERT Chart


Create GUI Profile Skeleton
(24,33,35)
Connecting to Microcontroller
7,15,21
3d interactive images
29,33,40
Storing data in database
17,29,32
Server Establishment
10,22,24
Data Download from Cloud
5,7,10
Testing
5,14,16