1 Introduction

1.1 Objective

Research suggests that there are as many as 3.8 million sports-related concussions in the United States every year and this number shows no signs of decreasing [1]. From high school athletics to the NFL, concussion rates are actually increasing annually. NFL athletes have remarked that if concussions don’t happen on every play, then they occur on every other or every third play. Consequently, athletes end up playing through concussions and not getting immediate care.

The main reason that there does not exist a system to better monitor concussions is because there are numerous factors that play a role, including individual genetics. In addition, there simply is not enough data to enable research in this area. Our project hopes to address a few of these obstacles.

In conjunction with TEAM 55, the goal is to design a wearable device for athletes that has the capability of collecting heart rate and accelerometer data, wirelessly transmitting, performing particular algorithms, and storing the data for future analytics in the long term. Our team will be responsible for the latter half of the project. Specifically, our team will read data from a microSD card, run our algorithm to gain insights, wirelessly transmit the data to both an application and a computer that can send the data to the cloud (Amazon Web Services) for long term storage. The
application will provide a user interface for either a coach or trainer. We hope that this device will provide insightful information that can be used in research for years to come.

1.2 Background

To date, a few systems do exist that try to address increasing concussions in athletics. For example, the Head Impact Telemetry System (HITS) was designed by Simbex in an effort to measure and record head impact exposure [1]. However, HITS, as well as other devices, only collect acceleration data. In addition, some of the devices try to predict concussions and alert coaches and/or trainers on the sidelines when a high-impact hit was made. Lastly, some devices are built into helmets, which might compromise the integrity of a helmet and would not be easily adopted by the NFL, for example.

Our design will be the first to simultaneously collect heart rate data accelerometer data. However, it is important to note that we will not try to diagnose concussions, as this is not possible to do at the time of impact and will require detailed analysis by qualified medical researchers and professionals. We will simply analyze our data to infer impact locations and rotation of the rigid body to help enable research.

1.3 High Level Requirements

- The sampling rate of data from the accelerometers should be 1000 Hz. Therefore, to achieve real time computation, the data from microSD must be able to process each sample point in 0.001 seconds or less.
- The processing algorithm will determine acceleration in six degrees of freedom for a rigid body.
The processed data will be displayed on an Android app and will be stored long-term in Amazon Web Services.

2 Design

![Block Diagram]

*Figure 1.1 Block diagram of the overall design.*

2.1 Block Diagram

The Input block is the source for the filtered data that will be received from Team 55 in the form of a microSD card. Although Team 55’s data will be required for the overall design, sample data is being acquired from simulations for testing. The microSD card will be inserted into a connector that is soldered to the board that will have SPI transmission traces to communicate between the microSD card and the microcontroller of the Processing block. The Processing block consists of a microcontroller IC that will process the data from the microSD card, run the
algorithm, and transmit the kinematic data to a mobile application/computer via the Bluetooth transceiver on the microcontroller. Since the goal of the project is real time data acquisition, the microcontroller must have real time implementation of the algorithm. Through Bluetooth, the data will be sent to an Android application as well as a computer which can send the data to AWS for long-term storage. The Power block consists of a lithium ion rechargeable 3V battery with a PTC fuse for excess current protection and an UV/OV lockout protection IC for undervoltage and overvoltage protection.

2.2 Functional Overview and Requirements

Input/Short Term Storage

The microSD card is an external device that will be providing us with the data that needs to be processed and transmitted. Since the microSD can be as large as 128GB, memory is not a limiting factor. We will not be creating the data on the microSD card, but will be laying out a microSD connector on the PCB in order to take the data off the microSD and process it with the microcontroller. The microSD card requires a voltage input of 2.7-3.6 Volts. The voltage being supplied to the from the lithium-ion battery is 3 volts. Therefore, the input voltage needs to be within 10% of 3 Volts. Additionally, the maximum frequency of SPI communication with this microcontroller is 12 MHz which is four times slower than the core clock speed of 48 MHz. However, the SPI speed should not be a limiting factor as, in theory, multiple data points can be read off the microSD card and stored on the microprocessor’s on chip memory. Also, in practice, data will be transmitted directly from the device to an application, bypassing local storage. In this case, if 48 MHz happened to be the limiting factor, a faster processor and/or faster communication protocol could be used to ensure scalability.
## Power

The power block consists of a lithium ion battery with a PTC fuse and undervoltage/overvoltage protection. The battery will be a 3 volt battery that uses the DC/DC buck converter of the microcontroller to step the voltage down to the appropriate levels. The microSD card is also capable of accepting this 3V source. However, the microSD card accepts 2.7-3.6 Volts whereas the microcontroller requires 1.8-4.2 Volts and the UV/OV protection IC accepts 2.5-34 Volts. Therefore, the limiting factor on the input voltage is the microSD card which requires the voltage to be within 10% of 3 Volts. Additionally, the microSD requires up to 200 mA, the UV/OV protection IC uses up to 125 μA, and the microcontroller IC uses up to 200 mA, so the total current required for the PCB will be approximately 400.125 mA. However, the battery will be capable of supplying more current than this and the PTC fuse will be set to fault at 500 mA in case there are additional board resistance losses. For power protection purposes, the undervoltage/overvoltage lockout protection IC will be used. In terms of an open or short applied to the circuit, the PTC fuse will protect the circuit in the case of a short. In the event of an open, the UV/OV protection would not allow the circuit to operate and no damage would be done.

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<th>Requirements</th>
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<tbody>
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<td>1. Supply voltage within 10% of 3 Volts</td>
<td>1. Use a multimeter to verify that the voltage is within 10% of 3 Volts</td>
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<td>Requirements</td>
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<tr>
<td>1. Supply voltage within 10% 3V</td>
<td>1. Use a multimeter to verify that the voltage is within 10% of 3 Volts</td>
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<tr>
<td>2. Supply 500 mA at 3 volts</td>
<td>2. Use a variable resistance load set to draw 500 mA to verify the battery can supply that current</td>
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**Processing**

The Processing block consists of a NXP MKW41Z microcontroller IC. The algorithm will be stored on the on chip flash memory and will receive the data to be processed from the microSD card using SPI communication. The SPI maximum clock speed on the microcontroller is 12 MHz. Ideally the data would be read and processed one sample at a time. But if the slower SPI communication speed slows down the algorithm too much then in theory more than one sample could be read and stored in the on chip memory before processing. The algorithm will calculate acceleration in six degrees of freedom, which includes three axis each for both linear and rotational acceleration from the given accelerometer data [3]. This processed data will be sent to the computer and Android app via bluetooth. The bluetooth transceiver built into the microcontroller will be used along with the IEEE Standard 802.15.4 2.4 GHz to create a wireless personal area network to communicate between the microcontroller IC and an app as well as a computer. On the app it will display the time locked relevant accelerations of the head along with the heart rate during the impact. The data being sent to the computer can then be uploaded to AWS for long term data storage.
## Finite State Machine

![Finite State Machine Diagram](image)

*Figure 1.2: A high level diagram for the FSM leading the microcontroller.*

The FSM shown in the high level diagram above will be in charge of coordinating the different parts of the design. Once the microcontroller is powered on, we enter, and remain, in the wait state until a microSD card is plugged in. Once a microSD card has been acknowledged, the FSM enters the load state in which we load the first batch of data to be processed. The actual processing occurs in the process state, which we automatically transition to at the end of the load state. It is in this state where the microcontroller runs the algorithm and processes the data. An immediate transition at the end of the process state leads the FSM into the transmit check state. In
this state the microcontroller simply checks to see if either a mobile device or computer is wirelessly connected and ready to accept a transmission from the microcontroller. If the FSM receives a “go” signal we move onto the transmit state, otherwise we remain in the transmit check state. In the transmit state the microcontroller transmits the processed data onto the connected app or computer and the FSM immediately transitions back into the load state. From there the microcontroller either loads in a new set of data to process or, if all the data has already been processed and transmitted, the FSM transitions back into the wait state until a new set of data arrives.

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<td>1. Proper state transitions and performed actions</td>
<td>1. Verify FSM behavior through testing.</td>
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**Algorithm**

In the field, the wearable device will have three tri-axle accelerometers and one heart-rate sensor. When our microcontroller loads this time-locked data, the processing engine will either (1) perform an algorithm to gather insights on the accelerometer data or (2) simply pass the heart-rate data into transmission. Our algorithm has one main objective: to infer the linear acceleration of the head’s center of gravity, as well as to infer the rotational acceleration of the head’s center of gravity. This results in six degrees of freedom that describe the motion of a rigid body upon impact. The acceleration at any point, \(i\) on the head, \(\vec{a}_i\), undergoing linear and rotational acceleration can be described by:

\[
\vec{\alpha}_i = \vec{\alpha}_i \cdot \vec{H} + \vec{\alpha}_i \cdot (\vec{\alpha} \times \vec{\alpha}_i)
\]
where $\vec{a}_i$ is the sensing access of the accelerometer, $\vec{H}$ is the linear acceleration of the head’s center of gravity, $\vec{\alpha}$ is the rotational acceleration of the head’s center of gravity, and $\vec{r}_i$ is the position vector of the accelerometer. All parameters are known to us except $\vec{H}$ and $\vec{\alpha}$. The following convex optimization problem will be solved either numerically using gradient descent, or analytically since the matrix is small enough to compute an inverse/pseudo-inverse:

$$\min_{\vec{H},\vec{\alpha} \in \mathbb{R}^3} \sum_{i=1}^{n} \sum_{j=1}^{m} \left[ \left\| \vec{a}_{ij} \right\| ^2 - \left( \vec{r}_{aij} \cdot \vec{H} + \vec{r}_{aij} \cdot (\vec{\alpha} \times \vec{r}_{ij}) \right)^2 \right]$$

where $n$ is the number of sensors and $m$ is the x, y, or z axis.

**Data Presentation**

If the user wants to view the processed data in real time, a mobile application will be responsible for presenting data sent wirelessly from the hardware. Software will be used to generate useful plots, such as waveforms and histograms, that will depict magnitudes of impacts and direction of head rotation. There will also be an added feature that will allow a coach or trainer to tie a player’s information to their respective data. This data will then be logged to AWS after being sent to a computer.

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<tbody>
<tr>
<td>1. Ability to communicate wirelessly using bluetooth</td>
<td>1. Verify that the application is connected to the microcontroller and displaying data</td>
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Long-Term Data Storage

Long-term data storage will most likely be in an AWS S3 bucket used for safe, low cost storage (free 20,000 get requests of up to 15GB per month). Put requests will be made from a computer (2,000 free put requests per month).

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<td>1. Ability to access data at any time</td>
<td>1. Demonstrate connectivity with AWS</td>
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2.3 Risk Analysis

The largest risk related to the processing block is the accuracy of the algorithm. Although it was carefully chosen due to its promise of reliable and accurate calculation of linear and rotational acceleration, we have yet to put it in practice. Since the main purpose of our design is to log accurate data, we must ensure that the algorithm produces accurate data. Because in the end, even if everything else works perfectly, the overall project won’t work if the data we generate is useless.

Additionally, the communication between the microSD card and the microcontroller as well as the bluetooth communication with the application and computer are going to be another risk of not completing this project. Nobody within our group has experience with these communication protocols so figuring them out could potentially be a large blocker. However, there is documentation and resources available about these communication protocols so hopefully these resources with be advantageous for the completion of this project.

3. Ethics and Safety

3.1 Ethics
Since our device is primarily a data logger/processor we do not foresee any major ethical concerns. As far as our data processing is concerned, we are not going to make any inferences or claims based on our data. Rather we are simply collecting and transmitting useful data that can be provided to other individuals or organizations to utilize in their research. Any claims or conclusions that are made based off of our data is not our ethical responsibility. We will go so far as to assure that the shared data has not been altered or tampered with in any way to support any particular study or conclusion. Additionally, since the data we are collecting is health information of athletes we can fall under the protection of HIPPA [2]. Under HIPPA (Health Insurance Portability and Accountability Act of 1996) the healthcare information of an individual, such as heart rate, is protected by federal law. An individual can choose to share their healthcare information with apps and companies such as ours and this ensures the protection of our data as well as the privacy of the athletes.

3.2 Safety

The only real piece of our design that could potentially harm someone is the lithium ion battery. A relatively small explosion or a small fire can be caused by sudden capacity loss from thermal runaway which could be caused by a short across the battery. Depending on how close an individual is to our device when such a failure occurs, there could be some minor injuries. To mitigate the risk of such an event and ensure the safety of our users we will include a PTC fuse to disconnect the hardware from the power source in the case of a short. This will also have the added benefit of protecting the rest of the circuit from damage. Also, since we are providing a detailed description of our inputs and outputs, all potential risks associated with our device are clearly defined. This minimizes any major risk of injury due to ignorance.
References


[2] "Your rights under HIPAA," in US Department of Health And Human Services,
   HHS.gov, 2017. [Online]. Available:
   Feb. 8, 2017.

   Available: