Head Impact Telemetry Data Logging System

ECE 445 - Project Proposal - Spring 2017

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1. Introduction

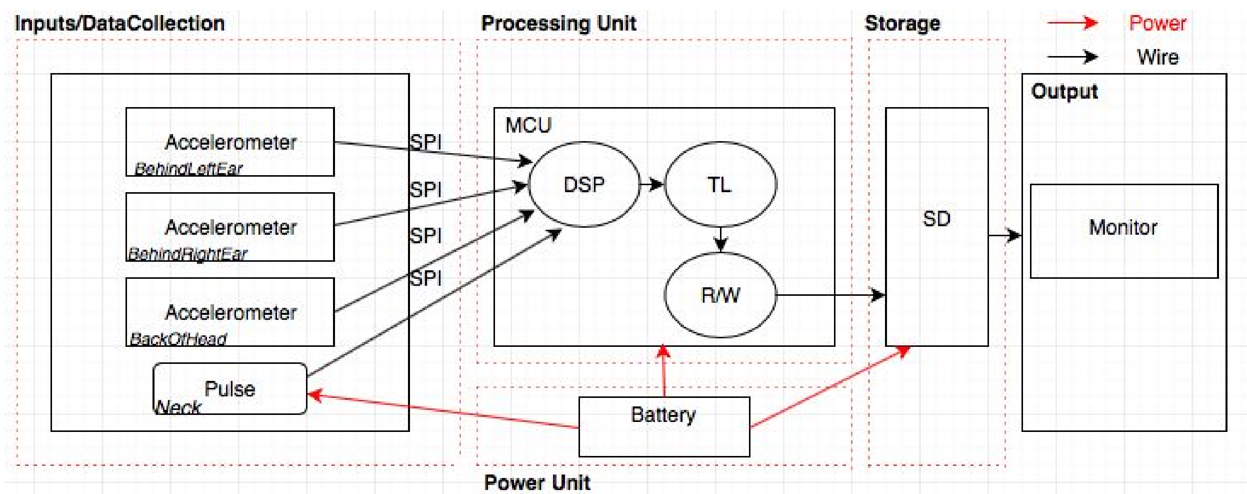
- **Background:** In the United States, the entertainment industry is vastly dominated by sports. Many of these sports are high impact sports, and the risk of injury must be considered. Football, lacrosse, and hockey, as well as many others, are among these high impact sports. According to the British Journal of Sports Medicine, there are an estimated two to three million cases of concussions in the States alone per year [1]. Most of these concussions are unreported and untreated. If the risk of concussion for each player were calculated in real time, then coaches and officials could be notified of any potential injuries as they happen, and medical attention could be given immediately. Many products introduced today analyze only the force applied to the head in these collisions, but do not focus on how the collision affect the different parts of the body. This data detection cannot give any insight to what is actually happening inside the body to better understand the effects of collisions to the head.

- **Objective:** The purpose of the Head Impact Telemetry System (HITS) is to monitor the acceleration of the cranium. Upon a sharp impact, the accelerometers should show a spike in acceleration. The device should have a preset threshold beyond which any acceleration higher than the threshold poses a risk for a concussion. At the same time, the HITS has a heart rate monitor as well to track the heart rate before and after impacts to provide insight on the effects of concussions on pulse. These two sensors are to be time locked before being stored to the SD card, allowing the two data sets to be relatable to each other when reviewed at a later time. Once the player has received medical attention, the time locked data can be transferred to an interface for a researcher to study the variations in pulse.

- **High-level requirements list:**
    - Sensors: The accelerometer must detect acceleration with an accuracy above 80%. The heart rate monitor must sense heart rate with an accuracy above 80%. Eighty percent seemed reasonable for the accelerometers because of the risk of mechanical error due to its spring based interior. Similarly, 80% is reasonable for the heart rate monitor too because it is limited physically due to variations from small movements. To verify this, we will set up experiments and compare the sensors' outputs to the controlled input value.
    - Wearability: The entire device will be worn on the body and must be reasonably small and light as to not obstruct movement or throw off the player's center of gravity. The battery has a radius of 20 mm, the SD card has dimensions of 24x32 mm, and the microcontroller 14x14 mm. Additional room must be provided for wires. Therefore, the dimensions of the wearable design will be smaller than 7x10x1 centimeters and have a mass of less than 300 grams.
    - Scalability: The design will be compatible for the user to add more accelerometers to the sensor array for more accurate and detailed data. Our project will act as a proof-of-concept for three accelerometers, but it will support as many as needed, as long as all sensors in the array feed into the same microcontroller so that all data streams can be time locked together.

- Power: The device must, at the minimum, have enough energy to last a game. The power usage of the accelerometers depends on the output data rate, so with the assumption that players can collide with a velocity of 20 meters per second and a maximum acceleration of 200 g, we should be sampling at a rate of at least 20 hertz. Three accelerometers sampling at this rate would consume about 600 microwatts. The pulse sensor takes about 20mW, and the microcontroller about 150mW. Since the device will be powered by a coin cell, the power usage should have a maximum of approximately 200mW for a lifetime of 3 to 4 hours.

2. Design



Block Diagram Overview
The system above can be broken down into four separate subsystems: inputs/data collection, processing, storage, and output. Moving from left to right: the input/data collection module consists of four sensors: three accelerometers (labeled where they will be placed around the head), and a pulse sensor (that will be placed on the individual's neck). The processing unit consists of our microcontroller and we broke this unit down into three separate subsystems: DSP, time-locked, and read/write. The third unit in the block diagram is the storage unit. This is where all the data will be located. This is a removable micro SD card mounted on the *printed circuit board.* The last section of the block diagram is not entirely in our design, but we wanted to include it to indicate that we will have an output monitor when we show our *proof-of-concept* to display all of the data we capture.

Wearable Design Module
The first three blocks in the diagram above consist of our overall *wearable design module.* The first block (inputs/ data collection) will be connected to a printed circuit board by wire and our printed circuit board design will consist of a power unit (battery), processing unit (MC), and a storage unit (SD). The *HIT Data Logging System* would ideally be able to scale to any athlete on this planet, but for the scope of this class we are going to focus on a few essential qualities of the device. The wearable design- specifically the four sensors- need to be small enough to fit comfortably yet strongly attached to the individual's skull.

The second thing we are going to focus on is making this wearable design as light as possible. The *printed circuit board* is going to contain the microcontroller unit for processing and storage as well as the power unit. The storage device will be a microSD that will cost negligible size and weight. The sensors will be mounted on three different locations on the head using a strong and safe adhesive material. There will be three locations for the accelerometers: behind the left ear, behind the right ear, and on the back of the head between both ears. Design should allow for player to achieve full range of motion of the head, neck, and upper body, as we are planning to attach sensors and PCB to areas of the body that won't be affected by their presence.
<u>Requirements</u>: Design should allow for player to achieve full range of motion of the head, neck, and upper body. Final mass of PCB should not exceed 300g, and the dimensions under 7x10x1 centimeters. We chose this weight based on the size of an iPhone which is 130g, and we estimated our lightweight design on these parameters. As far as dimensions, we wanted our design to fit on the player's back in a manner that will not impact performance. Specifically, we wanted it to fit between the shoulder blades on the back of the athlete and thin enough as to not protrude from the body.

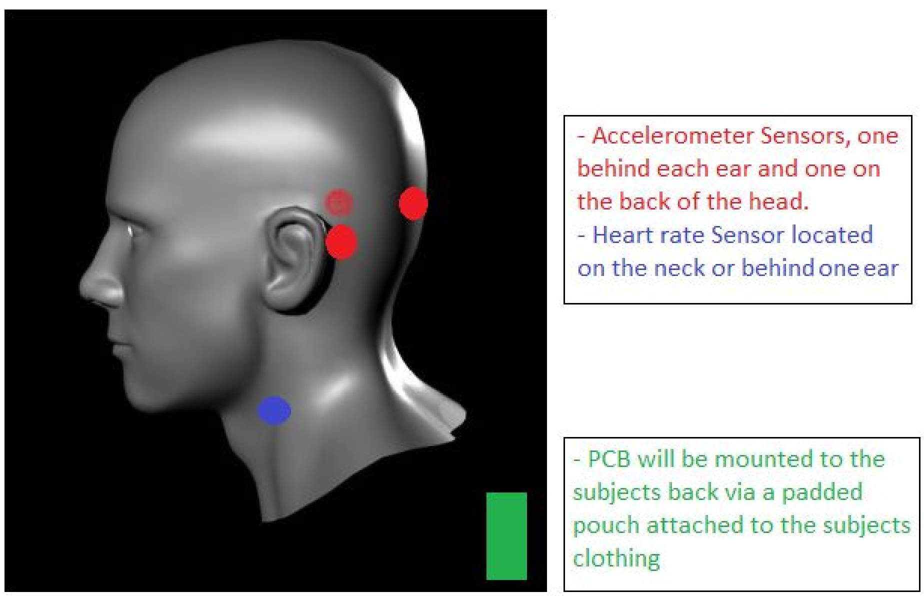
Storage Module
The storage device we are using is going to be a 512MB SD card. This is going to be the unit that stores the data from both sensors. It will be a removeable SD card that can be securely mounted on the PCB taking in data from the main MCU.
<u>Requirements</u>: Data storage should be up to 99% accurate on SD and take up no more than 512MB. The memory unit should be scalable so that we are able to allocate different sized chunks of memory based on the number of sensors used.

Power Module
The sensor module and the microcontroller both need power inputs. The goal of this device is to secure enough power to endure the entire cycle of an athletic sports game. The entire device will be powered by a CR2032 coin cell, which carries a charge of 220mAh at 3V.
<u>Requirements</u>: Provide power to the sensor module, the MCU, and storage unit. Accelerometer should receive 2.5V +/-.5V and .1uA, 35uA, or 145uA +/-2uA depending on activation state. These values are based on the ADXL375 accelerometer data sheet [3]. Heart rate sensor should receive from 1.6V to 5V +/- .5V and 4mA +/- .1mA. These values are based on pulse sensor specifications found on SparkFun [5]. MicroSD should receive 3.5V +/- .2V and 30mA +/- 5mA. The microcontroller has a absolute maximum power consumption of 300mW, so our design should ideally pull less than 150mW.

Sensor Module
The HIT system will use a total of four sensors: three accelerometers and one heart rate sensor. The accelerometers will be used to gather information on the linear acceleration of the head at 3 different points on the head. The heart rate sensor is used for gathering an athlete's pulse in real time. These sensor's outputs will then be fed as inputs into the PCB's MCU where they will be processed using DSP filtering algorithms. The sensors will also be powered by the battery located on the printed circuit.
<u>Requirements</u>: The accelerometers and heart rate sensors should output data above 85% accuracy. Based on the reviews posted on IEEE websites, the sensitivity of the sensors we chose seem to have imperfect accuracies of up to 15%.

Processing Unit
Our processing module contains our microprocessor unit. For this design we chose the MB9Ax5xR , which is part of the [FM3 32-bit ARM® Cortex®-M3] Microcontroller families [6]. The reason we decided to go with a 32-bit ARM MC is the fact that these processors have above average processing speed and they are great for low power consumption. We need an MC with low power consumption in this design because we are using small batteries to power our system. This specific MC has 16 multi-function serial interfaces configurable as SPI, UART, and I2C. This is crucial for our system because in the future we want scalability for our design. This controller also has a 12-bit ADC in case we want our sensors to output analog data.

Physical Design
Ideally we would like to have a total of two accelerometer sensors, one located on each side of the head with a heart rate sensor also attached to the head, neck, or ear. From these sensors we will have wires running to our PCB located preferably on the back of the subject, with padding for protecting the PCB as well as the subject. The accelerometers will be roughly around the size of 3x5x1 millimeters, heart sensor roughly 3x3x1 millimeters.



Risk Analysis
The module with the highest risk within our design would be the sensors module. Whereas the other modules would likely have terminal consequences in case of failure, buggy sensors would be much harder to detect and troubleshoot. Despite the verification of the integrity of the sensors before implementing them into the system, continual impact may cause deterioration. A failure in the sensors would cause the entire system to be useless, as the data it collects may not only be incorrect, but even sabotage all prior research in the subject. To minimize this risk, we must decrease the probability of failure in the sensor

module as much as possible. The sensors have to be secured tightly in place to prevent wiggling loose in extreme physical impacts.

3. Ethics and Safety

One ethical issue associated with our system is the intentional destruction of the device to prevent monitoring, a violation of code 9 in the IEEE Code of Ethics [4]. Given that the device will be mainly used for high impact sports, opposing players may specifically target the device in an impact. To avoid this issue, we will make the PCB as flexible yet sturdy as possible.

Since the device will be worn on the head, there is a risk of electrical shock. Our device will be powered by a battery, so the shock will not be lethal in any way, but the risk is still possible. The sensors we plan to use has a logic interrupt that we will ensure is functional to reduce the risk of electric shock.

Another possible source of injury from our device is burns, especially because of its wearable design. The device will be dissipating a maximum of 200mW, which will not be nearly enough thermal energy to burn the skin. In the case of an unexpected electric surge, we will implement a sacrificial fuse to break the circuit.

References

[1] Harmon, Kimberly G.; Drezner, Jonathan A.; Gammons, Matthew; Guskiewicz, Kevin M.; Halstead, Mark; Herring, Stanley A.; Kutcher, Jeffrey S.; Pana, Andrea; Putukian, Margot (2013-01-01). "American Medical Society for Sports Medicine position statement: concussion in sport". *British Journal of Sports Medicine*. 47 (1): 15–26. doi:10.1136/bjsports-2012-091941. ISSN 1473-0480. PMID 23243113.

[2] Ramasamy, Vairamuthu, Chethan Gowda, and Sivaguru Noopuran. "The Basics of Designing Wearable Electronics with Microcontrollers." *Embedded*. N.p., 17 June 2014. Web. 02 Feb. 2017.

[3] “3-Axis, ±200 g Digital MEMS Accelerometer Datasheet.” Retrieved February 08, 2017, from http://www.analog.com/media/en/technical-documentation/data-sheets/ADXL375.PDF

[4] “IEEE IEEE Code of Ethics.” (n.d.). Retrieved February 07, 2017, from https://www.ieee.org/about/corporate/governance/p7-8.html

[5] https://www.sparkfun.com/products/11574

[6] “32-Bit ARM® Cortex® -M3 FM3 Microcontroller MB9A140NB Series Datasheet” Retrieved February 08, 2017, from http://www.cypress.com/file/253411/download