G-Cap: Concussion Sensing Football Helmet

M.A. Scally, S.E. Gaston, K. Carter II, J.D. Flowers

***Abstract*—The G-Cap system is designed to be attached inside a football helmet. The system provides an immediate wireless transmission to a Tablet via Bluetooth that the player has experienced a head impact that could result in a concussion. The G-cap consists of a tri-axial accelerometer, an arduino microprocessor, a wireless transmitter, and two lithium ion batteries. The G-Cap is capable of sensing direction of impact as well as ±200 g's of force with ±10 g's deviation. The sensed impact data will be transmitted via Bluetooth and received by a Bluetooth enabled device. An Android based computer application will compile and display data through the tablet. This device is crucial in an attempt to curb concussions sustained on the football field. With the G-Cap, medical staff possesses real-time impact data allowing them to more effectively monitor their athletes.**

***Keywords*—Application Specific Integrated Circuit, Biomedical Communications, Bluetooth, Computer Applications, Data Structure, Electronic Components, Event Detection, Microprocessor, Physics Computing, Surface Mount Technology**

I. Introduction

A concussion is a traumatic brain injury that alters the way your brain functions. Effects are usually temporary, but can include problems with headache, concentration, memory, judgment, balance and coordination [1]. In football today, concussions are viewed as a serious medical mishap. The amount of damage these hits inflict on the brain affects people for the entirety of their lives. While it is not known the long term effects of these impacts, our design will provide real data to study. The G-Cap is designed to be attached inside the interior of a football helmet. The sensor provides an immediate wireless transmission to a Tablet computer, via Bluetooth, that the player has experienced an impact that could result in a concussion. This takes the guess work away from determining when to take a player off the field to seek medical advice. The G-cap device consists of a tri-axial accelerometer, an arduino microprocessor, two lithium ion batteries and a wireless transmitter embedded inside a football helmet. The accelerometer will sense an impact and if the impact registers greater than 50 g's, the transmitter will send appropriate data to a centralized receiver, typically controlled by medical staff. This technology now takes all the guess work away from medical staff when treating players for concussions.

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II. Design Approach

Much thought was given during the design phase for the G-Cap. The system must be compact and light enough to fit inside a football helmet, yet robust enough to sustain vicious impacts during play. The design could in no way alter or affect a player's performance, this being considered for both safety and competitive reasons. Therefore, all components for the G-cap were carefully thought out, rigorously tested, and once deemed satisfactory, implemented.

A. Integrated Circuitry

The implemented integrated circuit for the G-Cap consists of a tri-axial accelerometer, an arduino microprocessor, Bluetooth receiver, and two 3.7 volt lithium ion batteries. These components were first wired together on a breadboard in order to program the microprocessor, as well as observe the components working together.

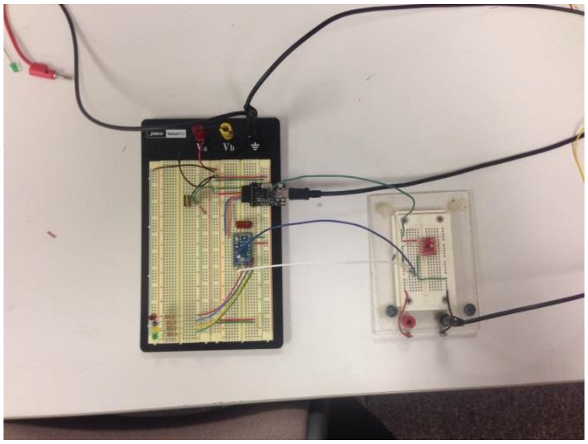


Fig. 1. The figure above depicts the G-Cap wired to a breadboard. Electrical circuitry was easy to manipulate in this state.

Once programming was complete, necessary components were soldered together, and then inserted inside the football helmet. The microprocessor and transmitter were soldered together with a piece of Styrofoam between the two acting as a buffer between the multiple electronic components ensuring unobstructed transmission. The accelerometer was secured to the top center portion of the helmet in order to allow for optimum sensing capabilities. The batteries were positioned at each rear lower portion of the helmet. All wires were wired underneath preexisting padding inside the helmet as to not interfere with the user. All components were secured using

3M adhesive electrical tape and Velcro. The Velcro was used exclusively for mounting the batteries.

B. Programming

The Arduino Pro Mini microprocessor was programmed using the arduino software provided by Arduino's website. The arduino software mimics C programming language. The microprocessor is the brain of the G-Cap. The microprocessor was programmed to sense an impact force, make a decision on whether or not that force was greater than 50 g's, then transfer appropriate data to the wireless transmitter. The decision to program the microprocessor to do nothing if an impact registers less than 50 g's played a crucial role for the G-Cap system for two reasons: It allows the G-Cap to ignore insignificant impacts that would never be considered dangerous in a football setting, and it is enabled to conserve battery life by remaining in an "active rest" mode instead of transmitting data constantly. The microprocessor was programmed to measure 60 data points in the X, Y, and Z direction, including the overall magnitude. The 60 data points will provide sufficient data for the G-Cap's android application to produce a graph of resultant linear acceleration vs. time, giving the user a clear indication of the impact sustained on the field.

C. Communications Link

The G-Cap uses long-range Bluetooth technology to transmit an impact up to 100 meters (328 feet) away. The wireless transmitter utilized in the G-Cap is an RN-41 FCC approved class 1 Bluetooth radio modem, with a robust link both in integrity and transmission distance. (100 meters) The modem is a low power consumption device, operating at an average of 25 mA, at a frequency of 2.4 - 2.524 GHz. The modem also possesses on-board voltage regulators, allowing it to be powered from any 3.3 to 6 VDC power supply. [2] This particular transmitter is designed to work well with the Arduino Mini Pro microprocessor making it a perfect fit for the G-Cap. The transmitter is paired with a Samsung tablet which will remain on the sidelines. If the G-Cap is stationed at the 50 yard line, it will experience a max distance of approximately 71 meters to either end zone. Class 1 Bluetooth is rated at approximately 100 meters; therefore, it made sense to choose class 1 for this application. [4]

Table 1. The figure below depicts the three classes utilized in Bluetooth technology.

Class	Max. Permitted Power		Typ. Range
	(mW)	(dBm)	(m)
1	100	20	~100
2	2.5	4	~10
3	1	0	~1

D. Android Application

The basic structure of the source code was the first step that had to be written. We chose to have the Android application open the connection between the Bluetooth transmitter and itself. A handshake was then completed and the channel secured. The Android application then requests if the transmitter has any information to pass to it. If the accelerometer senses a force threshold breach the processor will then transmit 60 points of data to the application. Next, the application takes this data and writes it into an array that is stored in the removable SD storage card.

A second part of the application reads this stored data. It calculates the magnitude of the forces and plots them versus time.

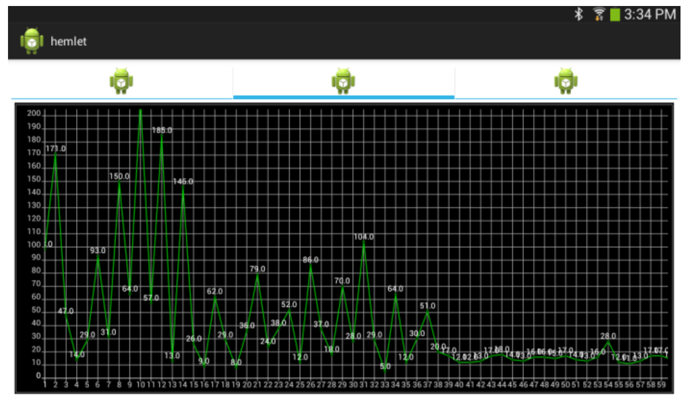


Fig. 2. The figure above depicts the application data screen displaying the magnitude of force over time.

The third and final part of the application takes the individual X, Y, and Z coordinates from the file and puts them through a testing procedure embedded within the code. Based on the magnitudes of the individual numbers an arrow will be uncovered in the application displaying the direction of impact.

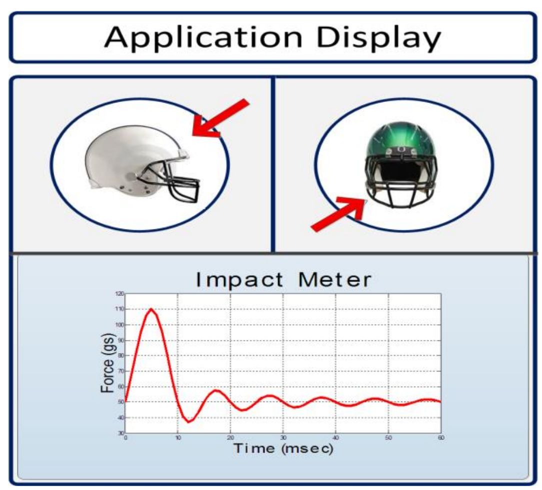


Fig. 3. The figure above depicts the application data screen displaying direction of impact.

III. Testing and Reliability

The design team ran into an issue early on in the design phase, which was simply; how can the user be sure that the G-Caps output readings are correct? If the G-Cap registers an impact at 110 g's for instance, was that particular impact actually 110 g's? In order to ensure accurate output readings, a pendulum style test apparatus was constructed to serve this purpose.

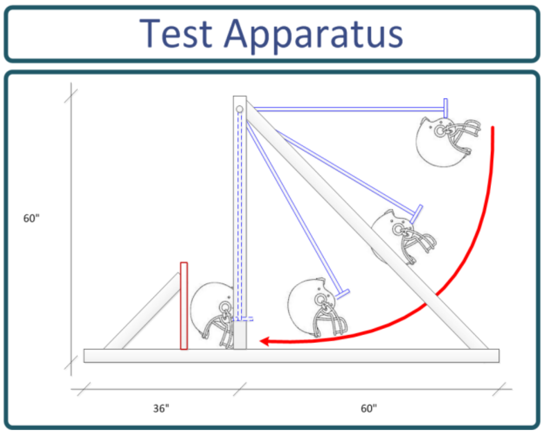


Fig. 4. The figure above depicts the pendulum testing apparatus used for quality control.

The testing apparatus was constructed of basic lumber and hardware. Height, weight, and speed were all predetermined, and using basic physics the force of the impact was easily derived. Knowing this data, the G-Cap was installed in the helmet, the helmet then secured to the pendulum, raised 90° (parallel to the floor), and released. Testing began at 70 g's and ended at 170 g's with 20 g increments. Each attempt included 20 impacts to obtain testing data. The data closely matched the nominal data derived using physics.

Table 2. The figure below depicts the results observed during the testing phase.

Attempt	Nominal values (g)	Avg. measured values (g)	Deviation (%)
1	70	74.6	6.57
2	90	97.1	7.89
3	110	117.6	6.90
4	130	138.8	6.76
5	150	159.1	6.06
6	170	179.5	5.58

IV. Equations

$$velocity = \sqrt{2 * gravity * height} \qquad (1)$$

$$acceleration = \frac{(velocity)^2}{2 * stopping\ distance} \qquad (2)$$

$$Force\ in\ g's = \frac{acceleration * mass}{gravity} \qquad (3)$$

$$Std\ deviation = \frac{measured - nominal}{nominal} \qquad (4)$$

V. Conclusion

With the growing interest in football with today's general population, the danger of concussions have become abundantly apparent. A concussion is a traumatic brain injury (TBI), resulting from a hit to the head which temporarily changes brain function. Most concussions occur due to direct impact to the head. However, impact to the body (i.e. blocking, falling, or tackling) which cause the brain to move quickly within the skull, may also attribute to TBIs. Symptoms of concussions are not the same for everyone and vary based on the severity of the brain injury. Concussion sufferers can exhibit a variety of physical, cognitive, and emotional symptoms. Those who have experienced a concussion are more likely to suffer another, especially if the injury occurs before the first concussion has had time to heal. This is where the G-Cap comes into play. The G-Cap will provide real time data of potential concussion level impacts inflicted on users, providing a front line assessment device to warn medical staff when a user experienced a significant or feasibly traumatic impact. The G-Cap is designed to be attached inside the interior of a football helmet. The sensor provides an immediate wireless transmission to a Tablet computer, via Bluetooth, that the player has experienced an impact that could result in a concussion. This helps take the guess work away from determining when to take a player off the field to seek medical advice. The G-cap device consists of a tri-axial accelerometer, an arduino microprocessor, two lithium ion batteries and a wireless transmitter embedded inside a football helmet. The accelerometer will sense an impact and if the impact registers greater than 50 g's, the transmitter will send appropriate data to a centralized receiver. Testing the G-Cap proved that the system is accurate up to ±10 g's.

VI. References

[1] Jonathon C. Edwards. (2007, Jan 11). *Concussions and Seizures in Athletics*. [Online]. Available: www.muschealth.com/neurosciences

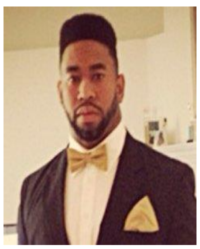
[2] *IEEE Standard for technology and information – exchange between systems*, IEEE Standard 802.15.3c-2009, Sept 11, 2009.

[3] Koen Mertens, Michiel Steyaert "A fully integrated class 1 Bluetooth 0.25µm CMOS PA," B-3001 Heverlee, Belgium. Rep. ESSCIRC 2002

VII. Biographies

Marcus Scally is an Aviation Electronics Technician in the US Navy, and possesses extensive knowledge pertaining to small component circuitry. His leadership capabilities obtained throughout his military career have contributed to the team greatly.

Stephen Gaston is another Navy veteran. He spent his time in the Navy as a nuclear trained Machinist Mate. His programming knowledge has been invaluable thus far.



Keith Carter possesses an extensive knowledge of digital signal processing and programming, which has helped with the communications link. Keith also was an offensive lineman for the Citadel Bulldogs Football team; his on field experiences provide real life insight as to what athletes experience throughout competition.

Jeremy Flowers was a Communications specialist in the US Army for seven years. His extensive knowledge of electronic communications and real life experiences with such technology has been a tremendous asset.