Technical Product Specifications

Class: Senior Design 1 (FALL2021)

Team: The Raiders

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Product Description

The concussion helmet is a product that acts as an effective safety feature for football players allowing others/medical staff to detect a player's concussion in real time.
It will be a regular football helmet with sensors and batteries attached to it in order for it to function. This product will utilize LoRaWAN and will be in good use to other sports or games as well.

Hardware Design Analysis

Hardware Specification

The main purpose of the hardware is to be durable enough to withstand high contact sports while not impairing the protection that the helmet provides the player. In order to not compromise the integrity of the helmet, the hardware needs to be as small as possible. A player getting tackled during a game can cause a concussion from the impact and force between both players, so the hardware must be able to withstand impact to the helmet .So the hardware device to register the impact must be able to survive over 150 g of force in order to ensure that the device doesn't break in the middle of use. Adding a sensor to the helmet will be a good way to help the football player to avoid concussion and head injury and above that detecting it with the sensor and program we run it with will help the medical staff take immediate action. In addition, in order to prevent the device from becoming hindered by potential WIFI issues, the device will have to communicate and transmit data through LoRaWAN.

Components

Accelerometer: ADXL377 SparkFun Accelerometer

The Sparkfun ADXL377 Accelerometer is a 3- axis accelerometer. This means it can detect acceleration on the x,y and z plane. The reason we chose this accelerometer is because it is small, low powered and can detect g's of up to 200 with a sensitivity of 6.5mV/g. It can also withstand temperatures ranging from -40 to 85 Celsius, a much wider range than what is expected temperature on the football field. The combination of the specs make it a perfect accelerometer for our use case.

ADXL377 SparkFun Accelerometer Specifications

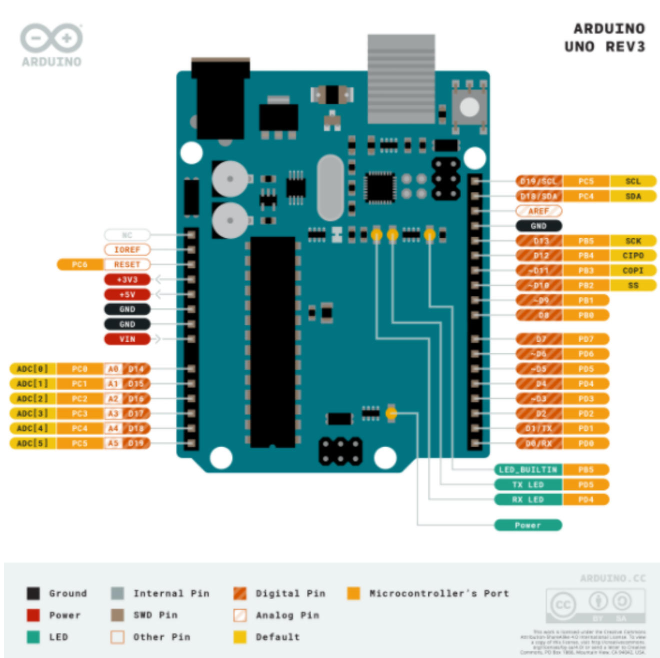
Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
SENSOR INPUT	Each axis				
Measurement Range			±200		*g*
Nonlinearity	% of full scale up to 180 *g*		±0.5		%
Cross-Axis Sensitivity[1]			±1.4		%
SENSITIVITY, RATIOMETRIC[2]	Each axis				
Sensitivity at X_{OUT}, Y_{OUT}, and Z_{OUT}	$V_S = 3$ V	5.8	6.5	7.2	mV/*g*
Sensitivity Change Due to Temperature[3]	$V_S = 3$ V		±0.02		%/°C
ZERO *g* BIAS LEVEL, RATIOMETRIC					
Zero *g* Voltage	$V_S = 3$ V, $T_A = 25$°C	1.4	1.5	1.6	V
Zero *g* Offset vs. Temperature					
X-Axis and Y-Axis			±12		m*g*/°C
Z-Axis			±30		m*g*/°C
NOISE PERFORMANCE					
Noise Density					
X_{OUT} and Y_{OUT}			2.7		m*g*/√Hz
Z_{OUT}			4.3		m*g*/√Hz
FREQUENCY RESPONSE[4]					
Bandwidth[5]	No external filter				
X_{OUT} and Y_{OUT}			1300		Hz
Z_{OUT}			1000		Hz
R_{FILT} Tolerance			32 ± 15%		kΩ
Sensor Resonant Frequency			16.5		kHz
SELF-TEST[6]					
Logic Input Low			0.6		V
Logic Input High			2.4		V
ST Actuation Current			60		µA
Output Change	Self-test, 0 to 1				
At X_{OUT}			−6.5		mV
At Y_{OUT}			6.5		mV
At Z_{OUT}			11.5		mV
OUTPUT AMPLIFIER	No load				
Output Swing Low			0.1		V
Output Swing High			2.8		V
POWER SUPPLY					
Operating Voltage Range[7]		1.8	3.0	3.6	V
Supply Current	$V_S = 3$ V		300		µA
Turn-On Time[8]	No external filter		1		ms
OPERATING TEMPERATURE RANGE		−40		+85	°C

Microcontroller: Arduino Uno Rev3

The microcontroller we chose is the Arduino Uno Rev3. We chose the Arduino Uno due to the fact that it has ample processing power to perform transmission of sensor data (data figures below). It also is very well documented along with having a robust system of libraries including the Arduino Software IDE that would aid us in the development of our product.It also does not require a high voltage at only 5V to function. More importantly, it is also low cost which means the cost of repair is low if the component is damaged on the field.

Arduino Uno Rev3 Specifications
- Measures 3.15” x 2.17” x 0.98” - Weight - 25 grams - Operating Voltage - 5V - Digital I/O Pins - 14 - PWM Digital I/O Pins - 6 - Analog Input Pins - 6 - Flash Memory - 32 KB - SRAM - 2 KB - EEPROM - 1 KB - Clock Speed - 16 MHz

Pinout Diagram of the Arduino Uno R3



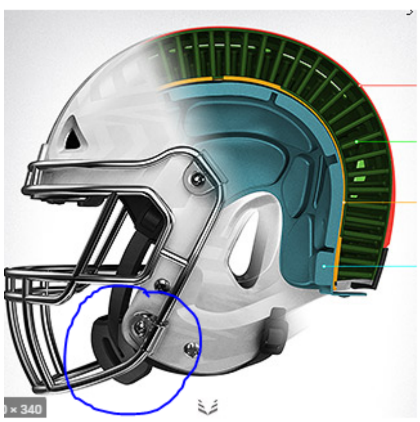
Hardware Limitations/Constraints

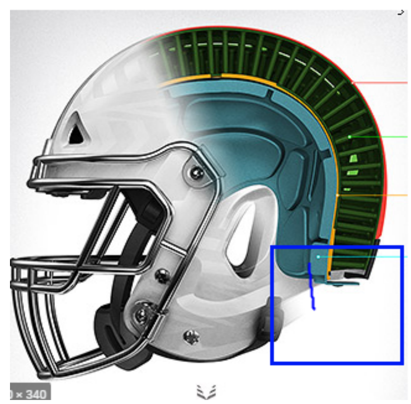
3-Axis Accelerometer

Although a 3-axis accelerometer can fulfill the purpose of measuring acceleration in all 3 planes/directions. It is incapable of detecting change in orientation. If the accelerometer is rotated from the position it was originally placed in, the axes orientation is rotated as well.

Component Placement on the helmet

The hardware/electrical components need to be secured to the helmet in a way that protects it from the collisions while also not posing a hazard to the safety of the wearer in the event of a collision. Currently, the only 2 viable options that we've found are either somewhere along the chin guard or at the base (lower back) of the helmet.





Hardware Alternatives

6- Axis Gyroscope

The issue regarding change in orientation brought by the 3-axis accelerometer can be solved by replacing it with a 6-axis gyro. The gyro would be able to measure acceleration in the 3 cartesian coordinate axes and also pitch, roll and yaw. With it, we would be able to detect a change in orientation of the helmet and its rate of turn. However, the main purpose of the product is to detect if the acceleration experienced by the player would result in a concussion. Using a 6-axis gyro and introducing pitch, roll and yaw into the equation might bring more complexities and factors without much contribution to the main purpose of the helmet. Further investigation and testing is required.

Adafruit Feather M0

A potential alternative microcontroller is the Adafruit Feather M0. The main appeal of this microcontroller is that it has built-in LoRaWAN compatibility.

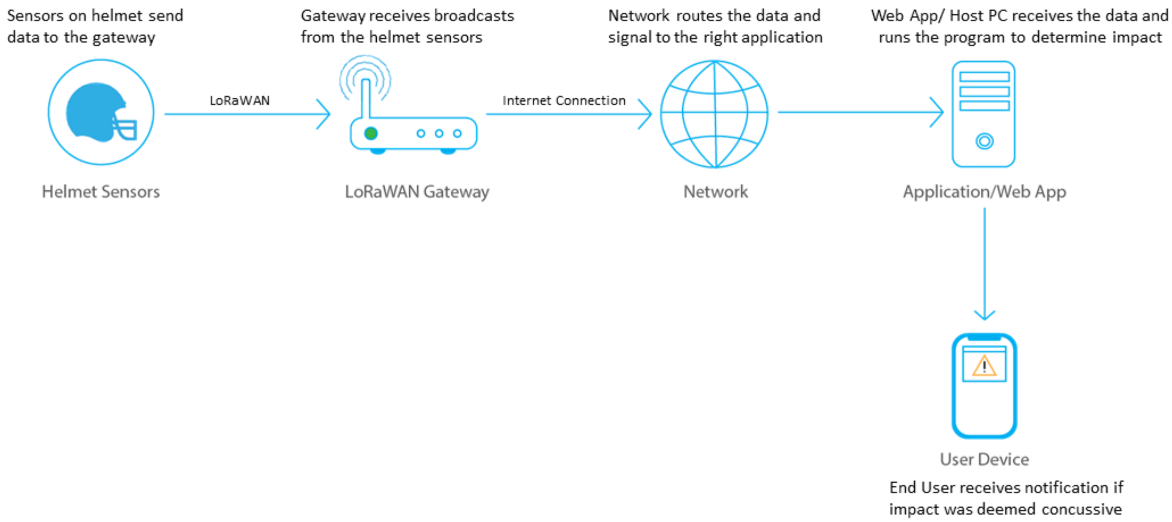
Adafruit Feather M0	Arduino Uno
- Measures 2.0" x 0.9" x 0.3" - Weight - 5.8 grams - Clock speed - 48MHz - Operating Voltage - 3.3V - GPIO pins - 20 - PWM pins - 8 - Analog Input Pins - 20 - Flash Memory - 256KB - SRAM - 16KB - EEPROM - None	- Measures 3.15” x 2.17” x 0.98” - Weight - 25 grams - Operating Voltage - 5V - Digital I/O Pins - 14 - PWM Digital I/O Pins - 6 - Analog Input Pins - 6 - Flash Memory - 32 KB - SRAM - 2 KB - EEPROM - 1 KB - Clock Speed - 16 MHz

Software Design Analysis

Software Design

As WiFi connection is unreliable and rare on the football field, our product will utilize LoRaWAN for the transmission of data from the sensors to the network where we can then route it to the application we use to calculate the resulting acceleration and send an alert if needed as shown in the diagram below.

At the moment of impact, the accelerometers in the helmet transmit raw sensor data to the gateway. The gateway then receives the LoRa message from the end device and forwards them to the network server. The network server then routes and forwards the data to the appropriate application. The host PC or Web application (to be determined later on) then receives the data and runs the program which takes the data from the sensors and calculates the resulting acceleration experienced by the player wearing the helmet and decides whether the impact is one that usually results in a concussion. If so, the program alerts the coaching staff via application who would decide on the appropriate course of action.



Software Components

LoRaWAN

LoRaWAN solves issues such as connectivity on the field and power usage for transmission from the sensors for us due to it being designed for the applications that require low power and large range.

LoRaWAN Features:

- Operates using open source software
- Uses gateways that reach areas across multiple kilometers
- Urban area average: Up to 5 km
- Rural area average: Up to 15 km
- Works indoors including multi floor buildings
- Optimal for devices with low data rates and power requirements
- Optimized to prioritize conserving battery life

Feature	LoRaWAN	Narrow-Band	LTE Cat-1 2016 (Rel12)	LTE Cat-M 2018 (Rel13)	NB-LTE 2019(Rel13+)
Modulation	SS Chirp	UNB / GFSK/BPSK	OFDMA	OFDMA	OFDMA
Rx bandwidth	500 - 125 KHz	100 Hz	20 MHz	20 - 1.4 MHz	200 KHz
Data Rate	290bps - 50Kbps	100 bit/sec 12 / 8 bytes Max	10 Mbit/sec	200kbps – 1Mbps	~20K bit/sec
Max. # Msgs/day	Unlimited	UL: 140 msgs/day	Unlimited	Unlimited	Unlimited
Max Output Power	20 dBm	20 dBm	23 - 46 dBm	23/30 dBm	20 dBm
Link Budget	154 dB	151 dB	130 dB+	146 dB	150 dB
Batery lifetime - 2000mAh	105 months	90 months		18 months	
Power Efficiency	Very High	Very High	Low	Medium	Med high
Interference immunity	Very high	Low	Medium	Medium	Low
Coexistence	Yes	No	Yes	Yes	No
Security	Yes	No	Yes	Yes	Yes
Mobility / localization	Yes	Limited mobility, No loc	Mobility	Mobility	Limited Mobility No Loc

ChirpStack

ChirpStack is a LoRaWAN network stack that is open source and allows us to manage our devices and gateways with a user-friendly UI.

ChirpStack Features:

- Dynamic Data-rate
- Supports private access by multiple organizations simultaneously
- Live Logs for transmitted data/events
- AES-128 Encryption/Decryption for data payloads
- API Integration/Web-Interface for existing infrastructures

Software Limitations/Constraints

LoRaWAN Constraints:

	Europe	North America	China	Korea	Japan	India
Frequency band	867-869MHz	902-928MHz	470-510MHz	920-925MHz	920-925MHz	865-867MHz
Channels	10	64 + 8 +8	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee
Channel BW Up	125/250kHz	125/500kHz				
Channel BW Dn	125kHz	500kHz				
TX Power Up	+14dBm	+20dBm typ (+30dBm allowed)				
TX Power Dn	+14dBm	+27dBm				
SF Up	7-12	7-10				
Data rate	250bps- 50kbps	980bps-21.9kpbs				
Link Budget Up	155dB	154dB				
Link Budget Dn	155dB	157dB				

LoRaWAN by design is meant for applications that require low power, low data rate and wide reach. Using LoRaWAN means that we need to limit our data throughput which could potentially interfere with our real-time application and increase latency.

ChirpStack Constraints:

ChirpStack is advertised as an out of the box LoRaWAN network manager but it still requires different components and user knowledge to be used to its full potential, such as:

- Needs a MQTT broker to publish and receive application payloads
- Needs PostgreSQL for the components to use for persistent data-storage
- Needs a Redis datastore for the components to use for non-persistent data-storage

Software Alternatives

Alert Delivery System via Cellular (Text Message)

As WiFi connectivity is the main issue on the field and not cellular service. We can potentially streamline our process and bypass the need for a standalone application whose job is to only alert the staff about a potential concussion and replace it with an automated text message to the appropriate staff.

Cellular Delivery

Pros	Cons
- Saves resources on development of application - Alerts can be sent to end users as long as they have cellular service (not needing to download an app)	- Relies on cellular network - No user interface/intractability and information provided limited by text message

Acceleration Calculation on microprocessor

If the microprocessor enables it, the calculation for resulting acceleration experienced by the player can be done on the microprocessor on the helmet itself instead of on a web application or on the host computer. This reduces the amount of data sent out by the helmet through the LoRaWAN network to just the command to send out an alert and relevant information.

Pros	Cons
- Potentially reduce data throughput through LoRaWAN network - Faster Real-Time calculation reduces the amount of waiting for webapp to receive and respond	- Heavily depends on microprocessor - Increased power usage by the microprocessor

TheThingsNetwork(TTN)

A potential alternative to ChirpStack is to use ThingsNetwork. They both essentially serve the same purpose of network and device management.

Pros	Cons
- Cloud based platform vs ChirpStack's standalone platform	- Cannot be directly installed onto Gateways - TTN fair use policy is more restrictive with data throughput compared to ChirpStack

Standards and Regulations

Helmet Regulations:

We will use the NFL helmet and to improve it we checked the CPSC (U.S. Consumer Product Safety Commission) the CPSC is an independent agency. According to the CPSC, consumer products are promoted as safe by addressing "unreasonable risks," developing uniform safety requirements, and conducting research into injuries and illnesses related to these products. The helmet will have to meet with the CPSC requirements. The CPSC requirements are that the helmet should be visible and the player can see in all directions, it should cover the athlete's head from the middle of his forehead to the back, and the helmet should have a chin strap. Also, if we are going to improve the helmet by adding the sensors and Arduino…etc) we will need to cover them.

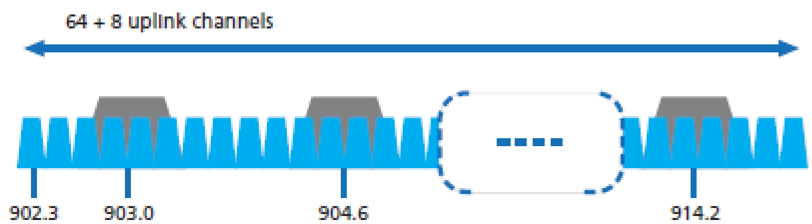
ChirpStack Regulations:

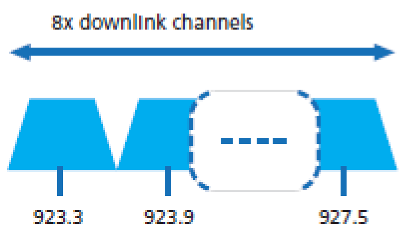
All components of ChirpStack are under the MIT license and are usable for commercial purposes.

Radio Frequency Regulations:

As we'll be using LoRaWAN to transmit data on the field, we would have to regulate our use of radio frequency to ensure that we adhere to FCC regulations. LoRaWAN does not violate any FCC regulations as it has 64 + 8 +8 (=80) channels as listed below.

- **FCC Regulations:**
  - No limitations on duty cycles
  - Max dwell time of 400msec per channel
  - Frequency hopping requirement of over 50 channels utilized equally in the ISM band (LoRaWAN uses 80 channels)
  - 64 x 125kHz uplink channels (From 902.3 to 914.9MHz in 200kHz increments)
  - 8 x 500 kHz uplink channels (From 903 MHz to 914.9MHz in 1.6MHz increments)
  - 8 x 500kHz downlink channels (from 923.3MHz to 927.5MHz)





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I have read the entire report and it meets my personal quality standards

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Member 2: Julian Tee

Member 3: Isuru Yapa

Member 4: Ali Alfadhli

Member 5: Andrew Johnson