HELMO: Hardware Design and Integration into a Smart Helmet

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***Abstract*—HELMO is smart helmet featuring a 9-axis Motion Processing Unit (MPU) and customized impact sensing array. When used in conjunction with our complementary motion recreation app, the system will aid healthcare professionals in the immediate diagnosis and assessment of acute traumas to the head. The contents of this report outline the hardware requirements for the project, the design of the Printed Circuit Board (PCB) and the practical integration into protective headgear.**

***Index Terms*— Motion Processing Unit (MPU), Force Sensitive Resistor (FSR)**

I. Introduction

According to recent studies conducted by the Department for Transport and Sport England, it is estimated that annually around 6 million residents aged 16+ cycle to work [1] [2]. This number is expected to increase in the coming years due to several green initiatives such as a greater number of cycle lanes and rising taxes on polluting vehicles. In 2015 there were 21,287 reported cycling related accidents, with severity ranging from mild concussion to fatal skull fractures and brain damage [3]. It is likely that an even larger number of these incidents may go unreported.

The current procedure for diagnosing head injuries consists of asking the patient questions about the incident, performing a CT scan if required and identifying the severity of the injury using the Glasgow Coma Scale (GCS). When medical professionals require details of the accident, the patient will often have very limited recollection. This can lead to inefficiencies when treating the patient as additional assessments must be carried out. Inefficiencies can be costly, with a CT scan in the UK costing on average £380 and $1000 in the US [4].

HELMO aims to assist with the medical evaluation of acute traumas to the head by recording a detailed account of the fall. This information is obtained from a collection of sensors integrated into the helmet. The data is then transmitted via a Bluetooth link to the user’s phone where it is uploaded to a server. The appropriate medical professional can then download this information from the server using their version of the app. The application is also able to recreate an animation of the fall from the perspective of the helmet to further aid diagnosis.

Using Machine Learning techniques in addition to various software algorithms, HELMO will be able to differentiate a fall from everyday riding activity. In the event of a fall HELMO can analyse the collected data and can provide recommendations for treatment. Such recommendations will include whether or not a CT scan is required and the magnitude of concussion likely sustained.

II. Challenge

In order to achieve the required functionality, the following data must be collected: acceleration (3-axis), angular velocity (3axis), direction and impact force. The critical information that will be derived from this data are impact angle, impact force, energy absorbed by the helmet, energy transferred to the user. If this data is not obtained with a high degree of accuracy and reliability it may provide misleading information and prove detrimental to the user.

In addition, the need to integrate the electronics into the helmet pose several design constraints. Crucially the integration of the electronics must not impair the integrity and functionality of the helmet. Furthermore, the helmet must still adhere to the appropriate safety standards with the integrated module. This will be achieved by making the unit as small as possible.

Given the sizing limitations, the device will still need to sustain its battery life for an appropriate duration. This requires that all components used should have minimal power consumption and an appropriate battery capacity is selected. Additionally, the module will have to sustain any impact that the helmet may experience through a fall

III. Related Work

There are several commercial smart helmet solutions available such as the Sena Smart Helmet [5]. This cycling helmet establishes a Bluetooth connection with the user's mobile phone and conveys information from healthcare apps. It is able to communicate heart rate and distance travelled as well as allowing the user to make calls and listen to music. This system illustrates good integration of electronics into a cycling helmet without impairing helmet functionality. The Sena helmet does not however feature any motion or force sensors as is required for our project.

Another similar commercial product is Hovding [6], the first airbag cycle helmet. Hovding uses advanced algorithms to differentiate between normal riding and a fall condition, activating the airbag accordingly. It is crucial that this computation is done quickly and in real-time, since if the airbag does not deploy the user would be put at serious risk. This approach differs from our application since our aim is not to prevent but diagnose an injury. The algorithms used for Hovding, however, will be very similar to what is required for HELMO.

Smart helmets are also an area of research, the Konnect is an Internet of Things (IoT) based cycling helmet able to detect and report accidents [7]. It monitors accelerometer data for erratic movements and in the event of a fall will communicate this to the cloud using a Wi-Fi enabled processor. The appropriate emergency authorities will then be notified through the cloud and will respond accordingly. This is a similar goal to our project, however the Konnect does not provide much information regarding the severity of the fall and would not be useful for medical evaluation.

IV. Hardware Components

Here the main hardware components are listed with reasons for the choice:

A. Motion Processing Unit (MPU)

The Invensense MPU-9250 is a 9-axis MPU with an integrated 3-axis accelerometer, 3-axis gyroscope and 3-axis magnetometer. It comes in a small 3x3x1mm QFN package and can operate from a 3.3V supply. The power requirement for 9-axis sensing is 3.7mA, which is significant in a low power application. Just using the 3-axis accelerometer alone however draws only 450µA. It should be possible to save power by using the 3-axis accelerometer to detect when a fall is about to occur and then recruit the other sensors to record the details of the fall.

Since multiple sensors are contained within a single package the design of the printed circuit board is simplified allowing it to be more compact.

B. Bluetooth Low Energy Programmable System on Chip (BLE PSoC)

For Bluetooth connectivity the CYBLE-014008 was chosen. This package is an integrated solution containing both a microcontroller and Bluetooth wireless communication interface with an 11x11mm footprint. This is convenient as it contains all the required hardware for Bluetooth such as the crystal oscillator and antenna, which would otherwise need to be implemented on the board.

The integrated microprocessor boasts 25 configurable GPIO connections with 8 of these usable as analogue inputs. This means we can connect up to 8 FSRs to the chip without additional multiplexers. The 256kB of flash memory is enough to store the data from the sensors without needing additional storage such as an SD card. The chip is also available as a development board to allow for rapid prototyping before the main PCB is produced.

C. LiPo Battery

To be used as a practical device, the helmet should have a battery lifetime of at least 1 day. If we assume that a longer than average day may contain 8hours of cycling, we can select a suitable battery capacity to accommodate this.

The current draw for each component is listed in the table below:

Component	Current (mA)	Number
Invensense MPU-9250	3.7	1
CYBLE-014008	4	1
INA2322	2.6	4

$$Approximate\ current\ draw: 18.1mA$$

$$18.1mA\ x\ 8hours$$

$$144.8mAh\ x\ 1hour$$

$$160mAh$$

This battery calculation is likely a large overestimation as this is the consumption during a fall condition. Battery saving techniques can be implemented during normal usage, such as using only 3-axis accelerometer and not measuring FSRs. This will result in a much smaller quiescent current draw. This battery capacity however is convenient for our given form factor. 160mAh single cell LiPos are available with dimensions 23x17x6.5mAh and should provide several days of usage.

D. Wireless Charging Coil

An implication of helmet integration means the device must be able to withstand the high impact forces that the helmet could be exposed to. This entails that the module should be made as durable as possible. External connectors such as a micro USB port for charging present weak points on the module where damage could occur. Outdoor usage also exposes the unit to rain and dirt, conditions that can impair the functionality of external connectors. The design choice was made to fully seal the unit to make it as robust as possible. Instead of a micro USB connector charging will be done via an inductive coil.

Wireless inductive charging is a technology inbuilt into most modern mobile phones using the Qi standard. The receiver coils used in phones are commonly available and produce a 5V output suitable for charging a single cell LiPo. There are various topologies for wireless power transfer using inductive coils [8] [9]. For this project a standard charging pad for a mobile phone will be used for convenience. This can be located at the bottom of a bowl structure into which the helmet can be placed upside down. This will enable optimal alignment of the coils to obtain most effective wireless charging.

E. Force Sensitive Resistors (FSRs)

Force sensors are dominated by three main technologies: Quantum Tunnelling Composite (QTC), Capacitive Sensing and Resistive sensing. Both QTC and Capacitive types are only widely available over small force ranges (<10N), much lower than those required for this project. Resistive sensors, on the other hand, can operate over a larger range of force, albeit with lower sensitivity. As these sensors are available cheaply, a large number can be deployed for increased accuracy and repeatability.

Another advantage to resistive force sensors is that they can be glued to a given frame. Any stress experienced by the frame will then cause a deformation in the force sensor that can be detected. If each force sensor is glued to the frame in this way, an averaging method will yield the incident force on the frame. This has the advantage that the force does not need to be applied across the comparatively small area of the sensor. The frame in this case will be the body of the helmet.

The force sensors we intend to use will be the CEA-06-240UZ-120. This is due to their compact size and linear response. Most other available FSRs are intended for touch based applications which require direct force and have a non-linear response. These sensors are also available with a significant discount form the manufacturer through their student program.

F. Instrumentation Amplifier

There are several methods of interfacing FSR sensors, these range from simple potential divider configurations to trans-impedance amplifiers and balanced bridges. The intended measurement circuitry, detailed here [10] [11], recommends that each FSR forms part of a Wheatstone bridge where the output of the bridge is amplified using an instrumentation amplifier and measured using the ADC on a microcontroller.

Considering we need to interface a total of 8 FSR sensors the current draw from the instrumentation amplifiers will be significant. It is therefore critical to select an instrumentation amplifier with a low maximum current draw whilst also being low noise. The INA2322 instrumentation amplifier by Texas Instruments meets these criteria with a typical consumption of 2.6mA. These are available in a small SOIC package with each containing two amplifiers allowing board area to be conserved.

V. PCB DESIGN

The PCB to contain all the electronic circuitry is currently being designed using Altium designer. The board dimensions being aimed for are 30x50mm. This will contain the BLE PSoC, 9-axis MPU, 8 Wheatstone bridges, 4 dual instrumentation amplifiers, 160maH LiPo battery and inductive charging coil. At this stage, we are awaiting finalisation of the prototyping, currently being completed on development boards. Once this is complete the finalised PCB design can get underway.

We intend to use the next day service offered by PCB train to obtain the board with an expedited response. The design will be double sided and utilize exclusively surface mount packages. This will be necessary to achieve the smallest form factor possible.

VI. HERMETIC SEALING

It is desirable to have the electronics unit fully self-contained with minimal external connections. This enables the device to be more robust and less susceptible to damage incurred through high impact forces. A hermetically sealed module is one that is completely airtight and therefore not vulnerable to damage from water or dust.

Once the PCB is fabricated it can be hermetically sealed using epoxy resin, with the battery and wireless charging coil encased. The only external connections that may be required will be the leads to the FSRs. Since the FSRs are a permanent connection they don't require a connector and therefore won't affect the hermetic seal.

It may be found through preliminary testing that the impact force is evenly distributed throughout the entire frame of the helmet. A single FSR is therefore all that is needed to obtain impact force. In this case, the sealed module can then be fixed against the frame of the helmet with no external wiring.

VII. CONCLUSION

At this milestone in the development of the project, the key hardware components required for the functionality of the system have been identified. Testing is currently underway on these components to ensure that they are suitable for the project specification. Once this process is complete and any necessary changes to the design have been made the PCB design can be finalised and sent off for fabrication.

The main concern regarding the project is that the sensors won't have enough accuracy to recreate the fall with high enough resolution. To improve this the results of multiple sensors can be compared to ensure that the data corroborates. For instance, the accelerometer data should support the FSR data and can confirm its validity.

Overall if the project is successful the technology can find many other uses outside of cycling. Motorcyclists and Horse Riders could potentially benefit from a slightly adapted version of HELMO. It may also be possible to design HELMO instead of an integrated solution into an attachable module that can be used with existing helmets. This would greatly broaden the target market as users may be reluctant to purchase a new helmet

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