HELMO: Acute Concussion Evaluation System

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Abstract: A proposal is made to integrate a 9-axis Motion Processing Unit (MPU) and custom impact sensing array into bespoke protective head-gear. 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. Through enhancing the medical evaluation, treatments can be tailored to the patient's needs with an expedited response.

I. Introduction

Annually, in 2011, 741,000 working residents aged 16 to 74 cycled to work in England and Wales[1]. As of 2014, there were approximately 11 million frequent cyclists (cycles at least once a month) aged over 18 years old. According to a report by Royal Society for the Prevention of Accidents, there were 21,287 total cycling injuries over a range of severity [2], including death, in the same year. In the same report, it stated "…head injuries, ranging from fatal skull fractures and brain damage to minor concussion and cuts, are very common injuries to cyclists. Hospital data shows that over 40% of cyclists, and 45% of child cyclists, suffer head injuries." From this, it is estimated that there were around 8,000 cycling injuries involving head injuries that required hospital visits.

To diagnose the head injuries, doctors will need to follow a series of procedures from asking questions about the incident to performing computerized tomography (CT) scan, and finally identifying severity of the injury using Glasgow Coma Scale (GCS) [3]. However, in many cases, when doctors required circumstances of the injury, the patient would not be able to remember details of the accident [4]. Therefore, if the cyclists' helmet could provide real-time information about the how the impact occurred, it would aid doctors in diagnosing the severity of the incident. In addition, should the helmet be able to measure and record all information of the impact, including impact angle, force, energy absorbed by the helmet and energy transferred to the user, it would aid doctors in deciding whether CT scans, X-rays, or other stages of the diagnosis procedure would be required. With each CT scan averaging approximately £380 [5] in the UK and more than $1,000 in the US, the helmet could promote better allocation of medical and financial of resources.

II. Helmets Background

Helmets can help attenuate the transfer of momentum and transfer rate of momentum (force) from an impact to avoid brain injuries [6]. They use a layer of crushable material to handle the majority of the crash energy. In the case of hitting a hard surface, the crushing of the foam can dampen the crash energy to extend the head's stopping time, hence decreasing the peak force applied [7].

The helmets are tested in laboratories to verify their safety. They are dropped down in guided free fall onto flat, hemispherical and kerb-stone anvils. A head-form, an object with similar properties and shape to the human head, is placed inside the helmet. The test head-forms contain accelerometers that plot the force transmitted as a function of time [8].

The helmet standard used today is EN 1078, and it has an impact energy potential of 90 joules for the large helmet dropped on a flat surface. This value is 110 joules for the older Snell B-95 standard. Impact energy is a good threshold to indicate safety and is defined as the total energy needed to fracture a specimen [9].

In contrast to conventional helmets, the world's first airbag bicycle helmet called Hovding offers a threefold increased shock absorbance capacity[8]. The airbag pops in the case of an accident using specialised algorithms that differentiate between normal riding patterns and falling[10].

To achieve equivalent shock absorbance capacity, the size of a traditional helmet would have to be three times larger. Hovding has a great advantage in that sense, as the airbag pops during the actual accident, this prevents a possible brain injury with minimal intrusion. However, in the event that the airbag doesn't activate, the user would be placed at an increased risk, whereas a traditional helmet doesn't depend on such mechanisms.

While more advanced helmet solutions, such as the one offered by Hovding, increase user safety, they do nothing to assist the user once an accident has occurred. In this project, we are attempting to decrease the time between the occurrence of an accident and the medical treatment offered to the user. We will achieve this using technology to provide us with a large volume of data, which can be analysed to mediate medical treatment in the most appropriate manner.

III. Software

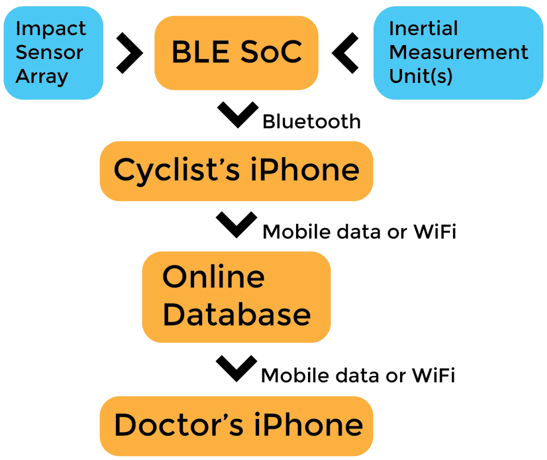

Figure 1: System overview

The software deliverables will consist of two main components. Firstly, our aim is to modify an existing helmet by embedding inside it one or more inertial measurement units (IMUs) and possibly an array of impact sensors. An embedded System-on-Chip (SoC) will be used to capture, pre-process and analyze the incoming data, which will be stored on-board over a rolling time window. Should an accident be detected in the analysis stage, the last recorded data interval will be saved and sent to a smartphone for further investigation.

Secondly, a smartphone app will be required. It will link to the hardware equipment via Bluetooth Low Energy (BLE) and to an external database using a REST [1] application programming interface (API). Mobile data or Wi-Fi will be used for network access. Upon receiving data from the helmet, the incoming accident will be synced with the database. A 'playback' mode will enable the user to visualize a reconstruction of the events up to the collision, as they were perceived by their helmet. This will give healthcare providers a better understanding of the sources and magnitudes of the impact experienced by the patient at the time of the accident.

Our smartphone app will be developed around the iOS platform. For achieving a 3D visualization of the collision, there are two obvious API choices: OpenGL (cross-platform portability, but suffers from reduced efficiency) and Metal (iOS only, but highly optimized). It is likely that Metal will be our prime candidate as no intention of an Android version of the app exists at the time of writing.

As the data being recorded may be considered confidential, each user will authenticate to the database with an account name and password. Crash data will be encrypted prior to its transmission to the database. Doctors will authenticate using special accounts that allow them to view their patients' accidents. A physician may add a user to their profile by username; confirmation will be required on the patient's side. Thus, the app will need to have two separate interfaces depending on the type of user profile i.e. user or healthcare provider.

IV. Hardware

The hardware is proposed to be integrated into the helmet and will consist of sensor arrays, microcontroller, a small Li-Po battery for power and charging coil. The choice for integration comes from the fact that the final product will need to endure repeated impacts, therefore any attachment would have to be made durable enough to withstand this. It is also desirable to have sensors located over a wide range of the helmet area for improved accuracy. This would be difficult to achieve with an attachable product. The disadvantage of integration is that care must be taken to ensure that the functionality of the helmet isn't impaired in doing so. This can be avoided by designing the module to be as small as possible.

The sensing elements are critical to the overall realization of the project. For our given application, we will need to measure the following to a high degree of accuracy: acceleration, impact forces, angular velocity and direction. If the system performs poorly in any of these aspects, it will likely prove ineffective in aiding the diagnosis of concussion.

To obtain acceleration, angular velocity and directional data, a 9-axis Motion Processing Unit (MPU) will be used. This integrates a 3-axis accelerometer, 3-axis gyroscope and magnetometer onto a single chip. The advantage to this all-in-one solution will be simplified calibration and integration compared with separate modules.

The accelerometer module will be able to provide an indication of impact force, since impact force is the result of a sudden acceleration. This data, however, may not be accurate enough to meet our specific requirements. Therefore, we plan to augment the readings from the accelerometer with additional force sensors.

Force sensing is 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, much lower than those required for this project. Resistive sensors, on the other hand, are able to operate over a large range of forces, albeit with lower sensitivity. As these sensors are available cheaply, a large number could be deployed for improved reliability. Large arrays of resistive sensors can also be purchased embedded into flexible sheet material, making them practical to implement within the helmet structure. We will likely conduct tests a wide range of sensor configurations to determine the optimal setup.

Seeing as the electronics will be integrated inside the foam padding of the helmet, it would not be practical to have an external power connector. For this reason, we will have an inbuilt wireless charging coil so that the small Li-Po battery can be recharged via a charging pad. Eliminating the requirement for external connectors will enable us to hermetically seal the unit, therefore making it more durable and robust.

V. DATA ANALYSIS & MACHINE LEARNING

This project aims at solving two problems, classifying a fall accurately against other everyday activities and assessing the severity to propose treatment, if that is required. The data that will be used to address this issue are motion and impact data.

Detecting a fall consists of a binary classification problem. Various products have been developed targeting fall detection [12][13] and have achieved a good accuracy without making use of machine learning techniques. Techniques such as inspecting the magnitude of acceleration and identifying key patterns that are unique within falls can be used to achieve a high detection rate. Including impact data in the classification of a fall is likely to increase accuracy further, providing a clear distinction between a fall and an accelerative motion. The supervised machine learning technique will also be implemented and tested, and its accuracy compared to that of basic algorithms in order to decide upon the most reliable classification technique.

Assessing the severity of a fall can be implemented by clustering motion and impact data. A set of classes can be defined, representing different levels of risk the user is in after a fall has occurred. Motion and impact data will be combined to formulate a machine learning algorithm that assesses the well-being of the user. In addition to raw data, some initial processing would allow the extraction of useful features from the data that could be used to improve the learning ability of the algorithm. For instance, monitoring the motion of a user after a fall has been identified could significantly contribute to the assessment of risk the user is in.

VI. EVALUATION

The evaluation of this project can be analysed into three main sections, each according the underlying functionality. These include determining the fall detection rate accuracy, characterizing the different injury classes and ensuring that the design of the helmet does not pose a risk to the user.

Supervised learning is going to be used for fall detection. Thus, the accuracy rate can be easily determined as all data will be captured in a fall or no-fall situation and this information will be available.

The most relevant way to assess injury classification is by replicating measurements used by doctors to classify head traumas. The two most common measurement techniques include the Glasgow Coma Scale and duration of loss of consciousness. Glasgow Coma Scale (GCS) is a 3- to 15-point scale used to assess a patient's level of consciousness and neurologic functioning [14]. The final rating depends on best motor response, best verbal response, and eye opening. Several features could potentially be built into the application to assess the severity of an injury on GCS scale. For instance, features could include asking the user to tap at specific locations testing his motor abilities and eye tracking using camera recognition technology. Duration of loss of consciousness can be easily checked using motion data provided by the accelerometer and can provide a clear indication that a severe injury has occurred.

Due to time constraints, we will not be building a helmet from scratch, but rather modifying an existing one. Thus, it is important to ensure that any modification made will not increase the risk of injury to the user. Helmet testing is a developed field with several regulations and required standards.

Safety standards and regulations have been underwritten to which helmet producers should conform to minimize risk. Therefore, every effort must be undertaken to conform to these standards.

VII. CONCLUSION

We believe our system is solving a valid problem and expect it will prove effective in mitigating response time and improving diagnosis for head traumas. The main difficulties we anticipate will be in calibrating the sensors to give accurate force readings for sudden impacts, as well as integrating the hardware and software components of the project. Overall, we are excited to commence work on the project in the coming weeks and are confident can deliver a functional prototype.

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