Head Impact Detection and Alert System

Design Team

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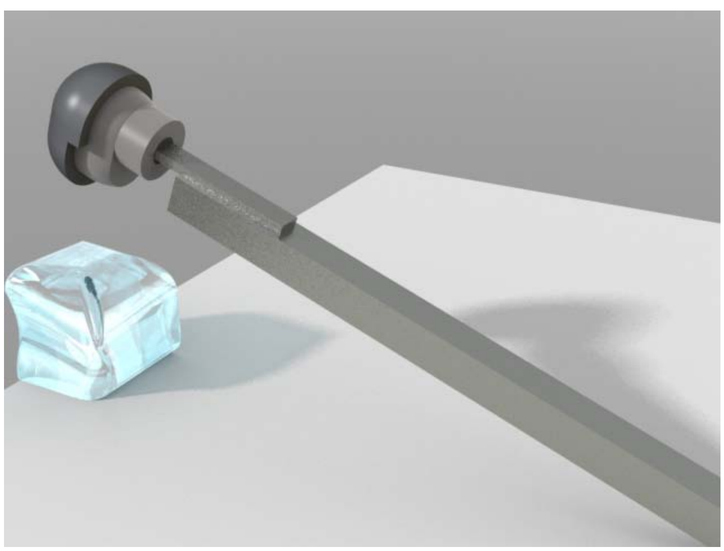
Abstract

Currently, Traumatic Brain Injuries (TBI) are identified once a patient has undergone significant medical testing and analysis to determine the severity of trauma. Due to the complexity of both the human brain and skull as well as the range of possible traumatic events it is virtually impossible to determine the severity of the TBI based on visual analysis. The current market includes several monitoring systems for TBI but the systems are very expensive or exclusive to military applications. The proposed design allows for the detection of TBI severity from exposure to impacts when wearing a helmet. The design also reduces the cost of the monitoring system and provides the user with approximate severity of the injury. A system was developed to determine the effects of an impact at the center of the head through the use of sensors positioned throughout the helmet. The ability of the product to provide immediate feedback to the user through the use of light emitting diodes (LEDs) or an audible alert, separates it from existing products. In the full implementation of the design, the feedback will be controlled by a microcontroller that will analyze the sensor data and categorize it based on severity of the impact. The system will be completely portable, requiring no external equipment. Due to time constraints this was not achievable for the purposes of this project, and the system remains attached to a computer for the data processing.



The Need for Project

The proposed design will provide instantaneous feedback to the user concerning the severity of a head impact.

Current products in the head protection industry are becoming more efficient in protecting the victim from serious traumatic brain injuries (TBI). The analysis and testing have led to the production and combination of newer materials that absorb the energy of the impact more efficiently. Although advances in protection have reduced the number of severe injuries, research into head trauma has shown that while immediate symptoms may not be present, severe injury, resulting in death, is possible. The issues lie in the lack of user awareness of the possible damage caused by varying severities of impact. In many situations the user shows no symptoms and does not seek medical attention, but may have severe head trauma, which may become fatal if left untreated.

The Design Project Objectives and Requirements

The objective of this project is to develop a self contained system that will alert a user of a critical impact to the head.

Proposed design outputs/function

The helmet impact detection system will focus on the area of winter sports impacts, and provide the user with magnitude information of a head impact without the use of external systems. Through the use of either audible indicators or light emitting diodes (LEDs), the user will be directed to seek medical attention. The primary operating range is 30-50g impacts. It is in this range that many concussions go undiagnosed because the user shows no immediate symptoms, but later the user may suffer more severe brain trauma if left untreated.

Design Requirements

There were five primary design requirements. First being that the sensors were required to operate in the low g range (~30 g's) and in the extreme g ranges greater than 150g's that can be seen in the professional skiing circuit. Secondly the rate of data acquisition had to be sufficient to allow the recording of several data points during the impact. Literature searches suggested that some impacts have duration as short as 12ms. Because of this small impact time frame, it was necessary for the sensors to acquire data at a minimum rate of 1kHz. This rate rendered enough data points for analysis. It was necessary to acquire 7 axes of sensor data in the helmet to account for the translational and rotational accelerations at the center of the head. All sensors were contained in the hard foam interior of the helmet and not interfere with the users head, ultimately maintaining the users comfort. The entire unit would be self contained, but due to time constraints this aspect was not achieved at this time.

Design Concepts Considered

Two main design concepts were conceived, one fully meets the project requirements.

Many designs were considered for this project but only two proved to be competitive when considering the most important criteria.

The first design consisted of a hard foam helmet with a plastic shell. Strategically localized areas were carved out of the inner foam padding. These sockets would accommodate accelerometers as well as a device to collect, process, and transmit the data. The integration of the sensing package and helmet will provide the user with the convenience of only carrying one device, which will provide both detection and protection.

The second design was conceived to allow the sensing package to be extracted from one helmet and integrated into another. The head guard would act as a "sock" and fit securely over the users' head, separate from the outer helmet. Like the previous design, sensors would be placed inside the foam padding.

Alternative "Sock" design

The two designs were assessed based on the following criteria listed in order of weighted value: display capability, sensing capability, workable volume, versatility, life cycle, estimated cost and comfort.

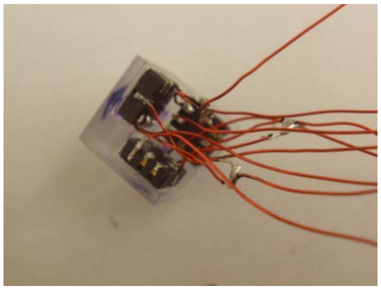
Recommended Design Concept

The final design concept is a hard foam helmet with a plastic outer shell. The unit contains sensors, a microcontroller, and an alert component as part of the system which will be tested and evaluated.

Both concepts were scored based on the design criteria but only one could be chosen to pursue for this project. The hard foam helmet was chosen as the final design because of how it scored on the decision matrix using the design criteria.

Design Description

The design of the helmet detection and alert system consists of three main components. The sensors attached to the helmet are be used to detect the impact. From these sensors, the acceleration in g's is recorded. The information from the accelerometers will be input into a microcontroller. The microcontroller will consist of an analog-to-digital converter, and will be programmable. The microcontroller

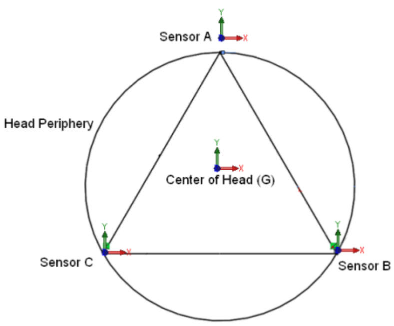


Tri-Sensor Module

will be programmed to analyze the impact data and send a signal to the component of the system that will alert the user and bystanders. The programming for the project was processed using LabVIEW software in a separate computer station. This programming accounted for the direct impact force and included calculations which took additional damage produced by rotational accelerations into consideration.

Analytical Investigations

An area of concern was the number of accelerometers used, and their arrangement in order to provide the most useful information.

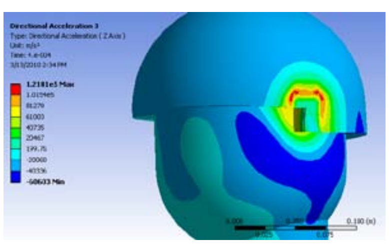


Sensor Placement Diagram

Sensors could only be placed around the periphery of the head (i.e. on the helmet as close to the head as possible). Such an arrangement provided data from which accelerations at the center of the brain could be calculated.

A variation of the standard kinematic relationship was used to determine that 7 accelerometers provided enough data to calculate the acceleration at the center of the head and account for rotational acceleration.

This sensor configuration was tested against analytical models and showed results with mid to low range errors. It was also analyzed using physical test data to determine the optimal placement of the sensors.

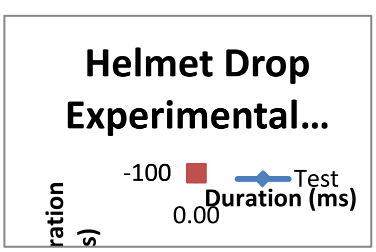


FEA Impact Simulation

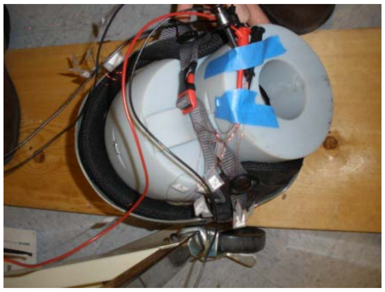
The impact test station setup was modeled and finite element (FE) simulations were run to determine the impact response. These FE simulations were correlated to physical test data, and used to predict optimal sensor placement and behavior of the brain during an impact.

Experimental Investigations

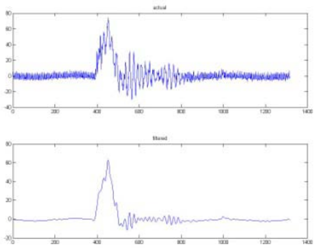
The test station consisted of a modular design to allow for multiple setups. The different physical tests were compared to the analytical simulations. Initially, a drop test was performed from at a set distance to determine the repeatability of the system. The test station was able to replicate the motion of an impact, where the system contacted the ground about a pivot point. The other test consisted of dropping a helmet from a known height. This test was done to determine the exact material properties of the helmet, and to verify the FEA rather than to simulate real life conditions. The test station included two springs that represented the human neck during



Helmet Drop Test vs. FEA



Head-Helmet Test Assembly



Filtered and Unfiltered Signals

these tests.

The electrical system of the test station consisted of a power supply, seven sensors, a wiring harness, a bread board, data acquisition module (DAQ) and a computer with LabVIEW.

When the g force exceeded a set threshold, LabVIEW was programmed to produce an output voltage that activated an LED of a specific color. By varying the LED color, the user would be made aware of the severity of the impact.

The sensors used were high impact, wide bandwidth accelerometers made by Analog Devices. They were chosen based on the following specifications which were critical to the design: dynamic range (+/-250g's), response frequency (22kHz), sensitivity (6.7mV/g), linearity (0.2% @ max) and operating voltage (3.5 – 5V).

Once the output voltage from the sensors was recorded for a set time, the data was saved and analyzed in Microsoft Excel or MATLAB. Comparing this data to the data produced by the finite element analysis gave an indication of the accuracy of the design.

Key Advantages of Recommended Concept

Other products on the market in the area of head trauma detection are not readily available to consumers. Many of them are used for military or large commercial applications, require significant supporting equipment, and with significant cost (i.e. RIDEL HITS football impact detection helmet $1400). The advantage of the proposed helmet design is that it would provide a head impact and early injury detection system for the everyday consumer. It has been shown that failure to detect brain injury early on can lead to compounding consequences, and even fatality. This design addresses such issues by providing a comparatively cost effective method for early brain injury detection and warning.

Financial Issues

While the price of the product may be more than the normal helmet, it is about a third of the cost of the current impact detection helmets on the market.

The prototype cost was $390, with the test setup costing $84. The cost of the current prototype only includes sensors and minor supporting electronics (wires, capacitors, etc.). All other parts were either property of the school or donated. The estimated cost of this prototype would be approximately $500. This includes pricing for helmet, sensors, microcontrollers, alert components and a power source. However, the price does not reflect the labor cost contributed to the prototype. The cost of each component would be reduced at increased volume of manufacturing, resulting in an estimate price of $350/unit.

The price is cost-effective when compared with existing products on the market, costing up to $1400.

Recommended Improvements

Improvements in the sensor configuration, developing a self contained system, and space for both power supply and microprocessor will be perused in future revisions.

In future developments several aspects would require alteration. Currently the sensors are all single axis accelerometers placed in mounting blocks to generate a single three axis accelerometer. If developed to further stages, the helmet will include pre assembled three axis accelerometers. This will reduce the size of the sensors and provide more accurate information. Another improvement would be complete integration of microcontroller, battery source and visual and/or audible indicators into the helmet. This would eliminate the need for an outside monitoring system and provide the user instant feedback. This microcontroller program may also take into account the history of impacts to the helmet system.