The Smart Helmet: A Practical Demonstration of Smart Environments in Sports

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Abstract. We present the Smart Helmet, a wireless sensor sports helmet for use in a sports wireless sensor network. The helmet is for the Irish sport of hurling and it gathers motion, impact and physiological data from the hurler during play. At present, the helmet is working with accelerometers, monitoring impacts and head movement in three axes, a pulse sensor and a temperature sensor. Data is collected by a microcontroller and transmitted using an RF transceiver. A mobile phone battery provides power. All the components are integrated between the helmet shell and internal padding. We are adding gyro sensors, a forehead PPG sensor for pulse and blood oxygen content measurement. The helmet's immediate application is in "smart coaching" and in impact analysis for improved helmet design. The data could also be used to generate multimedia re-enactments of play or for spectator viewing of player vital signs and impacts.

1.Introduction

The Centre for Adaptive Wireless Systems (AWS), based in the Department of Electronic Engineering at Cork Institute of Technology, investigates and develops concepts for hardware, software and network & system design for adaptive wireless systems. Hardware research focuses on the design of miniaturised wireless systems, particularly sensor nodes for wireless sensor applications. We have developed a modular concept for wireless sensor nodes that allows rapid customisation to a particular application. To demonstrate this, we have developed a wireless smart helmet, which transmits motion, impact and physiological data from a player. The specific sport chosen is hurling, an ancient sport (www.gaa.ie) mentioned in the earliest Irish legends and one that presents unique challenges from a wireless sensing viewpoint. It is superficially similar to hockey in that the ball is hit with a stick (the "hurley") but the ball (the "sliotar") can be played and hit on the run both on the ground and in the air and can travel at speeds up to 100km/hour. There is therefore a strong three-dimensional element to the sport and there may be frequent player-to-player, hurley-to-player and sliotar-to-player high-speed impacts. Regulations therefore demand that most players wear a helmet (www.mycrosports.ie) that can protect both head and face. The use of the helmet gives us the opportunity to embed

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a wireless sensor node in it but brings the challenges that neither player comfort nor safety can be compromised and that the node must withstand high 3-D accelerations from player motion and high g-force impacts. From an applications point of view we wanted to collect data on head acceleration (from impacts) for improving helmet design, player physiology and motion for both smart coaching and multimedia applications.

We therefore took the "standard" wireless sensor node structure (sensors, microcontroller, RF transceiver, antenna and power source) and distributed it about the helmet in the narrow gap between the outer hard plastic shell and the internal padding using a rigid-flex PCB "spider" to interconnect the electronics. A low profile mobile phone battery, sufficient for several hours of continuous use, provides power. This paper focuses on the practical issues of the hardware design, its integration into the helmet and on the results of field trials.

2.Requirements and specifications

The requirements for the smart helmet arise from its intended application in motion, impact and physiological monitoring. These dictate the use of 3-axis motion and impact sensors and sensors for collection of physiological data useful to coaches and doctors. The data from these sensors must be collected from a rapidly moving hurler for the duration of a training session or hurling match over the range of the pitch. The main requirement is therefore the inclusion of all the electronics, sensors and battery reliably in the helmet without disturbing the helmet design, reliability or player comfort. The distribution of the electronics needs to be correct e.g. the motion and impact sensors need to be positioned in the correct orientation to get the X, Y and Z components and the physiological sensors need to be attached to the player at the appropriate measurement points. The data from each sensor must be collected converted, labelled and sequenced for transmission to a base station. To allow use of the helmet in a wireless sensor network, the wireless link must facilitate spread spectrum communication with a base station. The specifications are:

- Typical g-force ranges are from ±2g for walking motion up to ±120g for typical hard sports impacts [1]. To get the required resolution for both motion and impact with an 8-bit A/D converter therefore requires two sets of accelerometers, one up 10g (giving a resolution of better than 0.05g) for running and the second up to 120g (giving a resolution of better than 0.5 g) of for impact.
- Accurate tracking of human motion in a vigorous activity such as hurling is a major challenge requiring a combination of acceleration, angular rate, compass and temperature sensors. This is beyond the immediate scope of the helmet project but we are including three axis gyro sensors in the helmet as a first step towards this application.
- Temperature: normal physiological range: 35-40ºC, resolution 0.5ºC
- Pulse**:** 30-200 beats per minute, resolution of 1

- SpO2 (blood oxygen): measured from pulse waveform, expressed as a percentage
- Battery lifetime, varying depending on the application but a minimum of three hours or the length of a training session.
- Transmission range needs to cover a playing pitch approximately 140m long and 85m wide

3. Helmet hardware

This section addresses the sensors selected for each measurement, the microcontroller, transceiver and battery, and the integration of all of the hardware into the helmet.

3.1 Sensors

Motion and impact

Motion is typically measured using a combination of accelerometers and gyros to be able to obtain motion data in all degrees of freedom. Tilt, inertial acceleration, shock and vibration can all be measured with an accelerometer. These sensors are now readily available in miniature IC packages using MEMS technology and with g-ranges up to ±250g. Impact can be measured using accelerometers or piezoelectric sensors. Accelerometers will measure head acceleration from an impact anywhere on the helmet; we decided to use accelerometers for measuring impact as well as motion. We are currently using Analog Devices ADXL278 50g accelerometers (one dual axis and one single axis) for both motion and impact. Fig 1 shows the typical output from the accelerometers placed inside the helmet after being impacted by a sliotar, displayed using MATLAB.

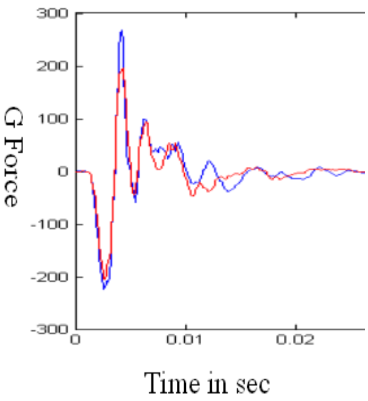


Fig. 1. Impact of a sliotar on the helmet

Physiology

Temperature

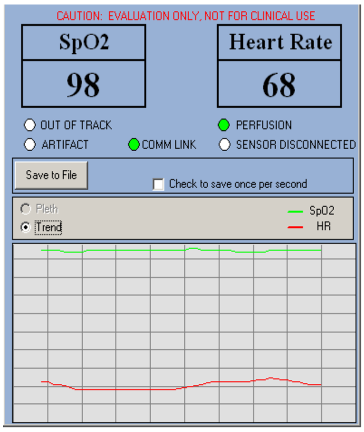
The RF transceiver selected (see Section 3.5) comes with a temperature sensor integrated. The required sampling rate is every 30 seconds.

Pulse

For basic pulse monitoring, we are using a simple ear-clip similar to those found on exercise machines. The ear clip contains an IR LED and photodiode on either side of the earlobe. Blood flow modulates the light level transmitted through the earlobe. The signal needs to be filtered and amplified before going to a microcontroller. The required sampling rate to get sufficient resolution of the pulse waveform is 15Hz.

Pulse oximetry

More useful than basic pulse is the collection of a PPG (photoplethysmography) signal. This is obtained in a similar way to ear lobe pulse using optical sensors but two LEDs at different frequencies are used allowing not only pulse but also blood oxygen content to be collected. The sensors are typically attached to a finger or to the forehead. For the helmet, the forehead sensor is ideal as it can be further secured using a sweatband. The forehead sensors are commercially available as are miniature circuit board modules for signal conditioning. We selected the 8000R reflectance sensor from Nonin and their OEM III module. Fig. 2 shows a screen shot from the typical output of the Pulse and bloody oxygen sensor received by the base station displayed on a laptop, the trend of the heart rate (red trace) and SpO2 (green trace) is also shown.



CAUTION: EVALUATION ONLY, NOT FOR CLINICAL USE

SpO2 98

Heart Rate 68

Fig. 2. Screen shot of Pulse and SpO2 output

3.2 Microcontroller

The main requirement on the microcontroller is to be able to sample all the sensors at a sufficiently high rate to make the data useful. For all the sensors in the helmet, this translates to a minimum clock frequency of 4MHz.

3.3 Transceiver and antenna board

The transceiver will need a minimum data rate of 36Kbps to transmit all the data from the microcontroller, a range of at least 100 meters and multi-channel capability. At present we are transmitting at 9.6Kbps with the accelerometers and ear-clip pulse reader in the helmet. For the antenna, the main requirement is to be omni-directional and low profile to fit in the helmet. We chose a Splatch 50Ω surface mount antenna with a gain of -2 dB. With maximum RF power from the transceiver, this antenna gives us a range of about 200m. The same transceiver is used as a receiver in the base station.

3.4 Battery

The battery needs to be light and low profile with a high power density, making a mobile phone battery is ideal. We chose a battery from a Nokia 2650 phone with a capacity of 820 mAh.

3.5 Hardware integration

We are using a PIC 16LF877 at 20MHz with 8K x 14 words of program memory, 368 x 8 bytes of RAM, 10 bit ADC and 8 analog channels which can be connected up to 8 sensors. We chose the Analog Devices ADF7020 working in the 868MHz ISM bands with a max throughput of 200kbps. At present the microcontroller, RF and sensors are connected using ribbon cable. Fig. 3 illustrates a typical hurling helmet from mycrosport and the basic outline of the sensors and electronics in the helmet.
We will be integrating the sensors, microprocessor and PPG onto flexible printed circuit board (“FlexPCB”), so it can adapt to the contours of the helmet.

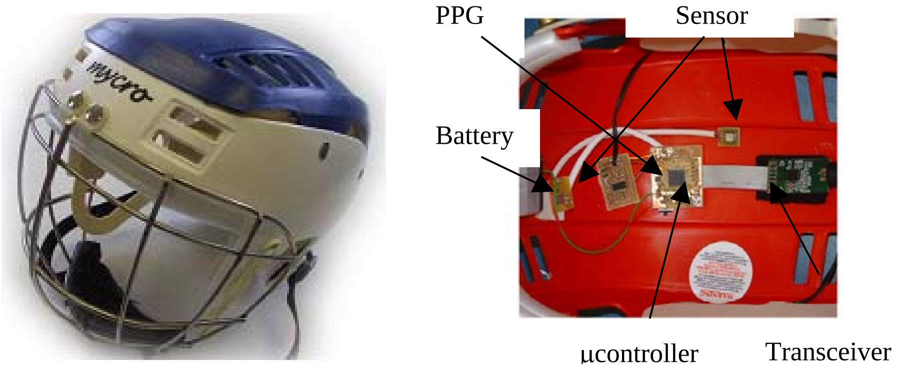


Fig. 3. Standard hurling helmet and Integration of electronics and battery in helmet

4. Software

Each sensor is connected to an A/D channel on the microcontroller, where they are sampled consecutively; the bytes are then sent serially to the transceiver, which transmits the signal at present at 9.6Kbps. The microcontroller also takes care of correct data sequencing and labelling. A base station connected to a laptop USB port then receives the signal. A LabView program separates the bytes into their correct waveforms, acceleration, pulse, temperature, angle and displays them in real time.

5. Field trials

We initially tested the helmet in the lab, simulating motion, impacts and battery discharge monitoring. We then moved to a gym treadmill and finally outdoors. The helmet has been recently tested by Cork Senior Hurler, Ronan Curran (www.rte.ie/tv/scope) and found to be comfortable and capable of working in a typical training session.

6. Ongoing work and planned applications.

So far, we have integrated the accelerometers, ear lobe pulse, microcontroller, transceiver and temperature sensor, antenna and battery in the helmet and these are working reliably. We are in the process of adding the gyros and pulse oximetry sensors, work which will be completed by the end of March. We will then be carrying out more comprehensive reliability testing. We then plan to apply the helmet in collecting data to improve helmet design, for smart coaching and for multimedia applications.

7. References

[1] Analysis of Real-time Head Accelerations in Collegiate Football Players. Stefan M. Duma, PhD, Sarah J. Manoogian, BS, William R. Bussone, BS, P. Gunnar Brolinson, DO, Mike W. Goforth, MS, Jesse J. Donnenwerth, MS, Richard M. Greenwald, PhD, Jeffrey J. Chu, MS, and Joseph J. Crisco, PhD