Electrical Cardiac Monitoring in the Head for Helmet Applications

Andres L. Bleda[1], Rafael Maestre[1], Björn Schmitz[2], Christian Hofmann[2], Jose M. Nacenta[3], Guadalupe Santa[1], Soledad Pellicer[1], Vivien Melcher[4]

[1]CETEM Technological Centre, Yecla, Spain
[2]Fraunhofer Institute for Integrated Circuits IIS, Erlangen, Germany
[3]NZI Technical Protection S.L., Yecla, Spain
[4]Fraunhofer Institute for Industrial Engineering IAO, Stuttgart, Germany

Abstract

In order to improve the emergency response of medical services to motorcycle accidents, the EU-funded i-VITAL project has developed an integrated system for providing real-time vital sign readings to emergency teams so that an adequate emergency response can be prepared in advance. The use of helmets is compulsory and they already include other enhanced functionalities (such as Bluetooth hands-free headset, or even GPS support). However, ECG has been performed almost solely through skin contact to both sides of the body, whereas direct electrical heart signal monitoring (ECG-like) in helmets remains an unsolved problem.

This paper presents the work and results on ECG-like measurements in the head area using EPIC sensors. This work was part of the i-VITAL project research, with the goal of constructing a novel vital sign monitoring system for seamless integration into helmets.

1. Introduction

In the case of an accident, motorcycles are much riskier than other modes of road transport. "More than 6500 motorised two wheeler users die each year in the EU (15) and the risk of death for motorcyclists is 20 times that of car occupants" [1]. The main reason are well-known: higher power-to-weight ratios (higher speeds and accelerations), inherent instability, harder to be seen than bigger vehicles, direct exposure of rider to impacts...

In 2014, PTW (powered 2-wheeler) riders accounted for 18% of all road fatalities in the EU [2]. The immediate availability of real-time rider status information and accident details (e.g. location, severity) will greatly contribute to a fast and adequate emergency response, which would lead to a reduction of the number of fatalities.

Accurate heart monitoring can be a key piece of information crucial in most severe accidents. Since the helmet use is compulsory, it is a reasonable device to integrate heart monitoring. Most of the currently available solutions are LED-based (e.g. Spree's Smart Headband, LifeBeam's Smart Helmet or Jabra Sport Pulse). However, to the best of our knowledge there is no practical ECG-like monitoring, that directly measures the electrical signal derived from the heart beat in the head area. The only exception is the cardiotocography (CTG) that uses a "fetal scalp electrode" for heart monitoring of babies in the mother's womb.

EPIC's electric potential sensors [3], developed by Plessey Semiconductors, have a very high impedance and high sensitivity making them ideal for different types of biological sensing. EPIC has been successfully used for dry heart monitoring in the body, arms and hands, even with no direct skin contact through some clothes. These features make them ideal for testing heart monitoring in the head area and have been chosen in this work.

This paper starts with a brief description of the i-Vital system and its main components and features. Then, it presents the research tests that were performed to identify the head zones where the ECG-like signal can be measured with the highest quality while using helmets as the integrator element. The actual results are presented and discussed. Finally, we show that ECG-like monitoring with EPIC sensors can be used for accurate heart rate measurement in laboratory conditions with no movement. The paper finishes with some conclusions.

2. i-VITAL system description

i-VITAL [4] is an EU-funded project that aims on enhancing rider eCall with vital data of the riders [4] to overcome the limitations of existing motorcycle eCall systems. eCall is an European-level initiative intended to bring rapid assistance to motorists involved in a collision anywhere in the European Union [5]. The i-VITAL eCall message will be compliant with established eCall standards [5,6], but will go beyond it by providing not only information about the severity of the accident, but will also enable access to the health condition of the

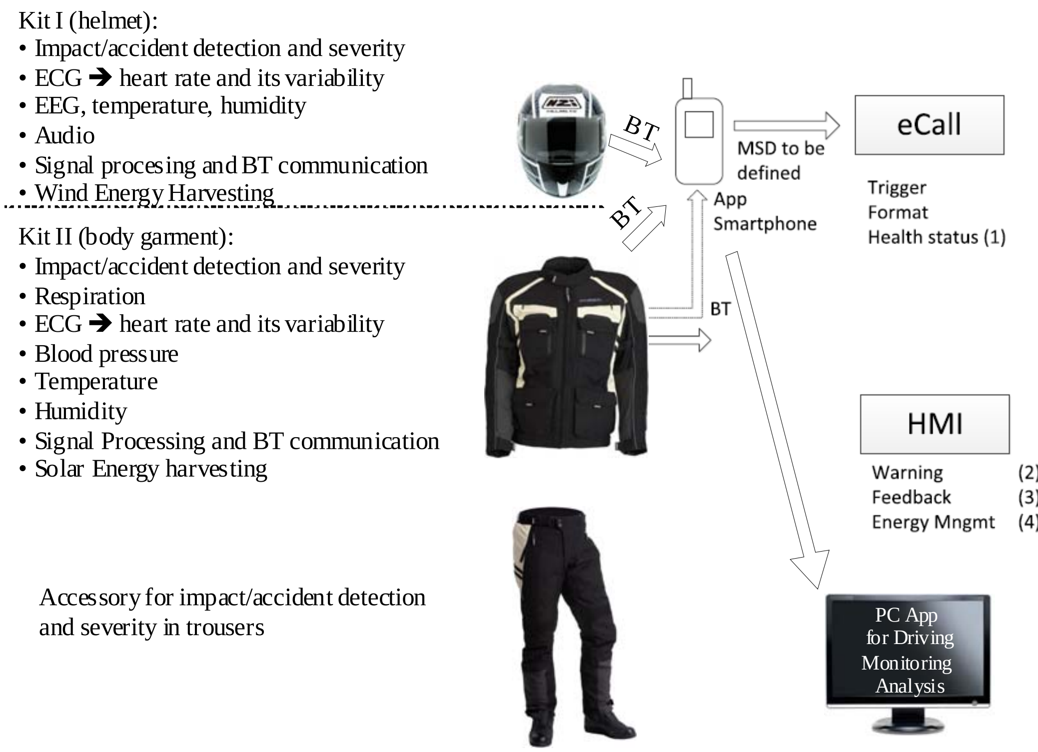

Figure 1. i-VITAL components

helmet/garment user. Vital signs information after an accident can be used by medical services in order to prepare an adequate emergency response. The i-VITAL system featuring vital sign monitoring and accident detection will be seamlessly integrated into helmets and garments.

The core of the i-VITAL system (Figure 1) is formed by 2 i-VITAL kits (kit1: helmet, kit2: garment) equipped with bio-signal sensors, and the user's mobile phone running an Android application. All components are linked via Bluetooth Low Energy (BLE).

An emergency voice and data call (eCall compliant) is triggered after an accident is detected. Its Minimum Set of Data (MSD as defined in [6]) is enhanced with vital data information.

Additional features of i-VITAL include energy harvesting for non-stop operation, and a smartphone app [7] that provides health monitoring, warning and activity feedback.

3. Experimental setup

3.1. Hardware description

The Plessey Demonstration Kit PS25003 EPIC [8] was used in all the experiments. The kit is made up of:

- a control box that includes a data acquisition and filtering circuits (low-pass and 50Hz rejection), as well as a USB interface to PCs
- two PS25101 EPIC sensors [9]
- software application for system configuration, acquired data filtering and real-time data visualization.

3.2. System configuration

In all the experiments the following configuration has been used:

- Control box enables the low-pass and 50Hz rejection filters, and uses a gain of 10x.
- Software application is configured in differential mode and simultaneously uses a 6th order low-pass filter with a cut-off frequency (fc) of 40Hz, and a 3rd order high-pass filter with fc=200mHz were used.
- A sample rate of 250Hz is used.

3.3. Tested sensor locations

The pair of EPIC sensors have been placed in different locations in the face and neck areas (see Figure 2) with direct dry contact over the naked skin of a person in sitting position, without any noticeable movement. These locations are easy to access from a motorcycle helmet and symmetrically positioned.

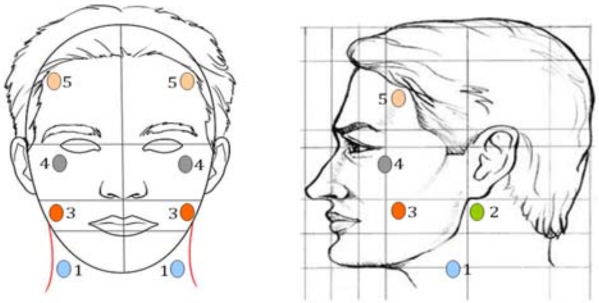

Figure 2. Sensor locations in experiments

4. Experimental results

The following graphs (Figure 3 to Figure 9) show the obtained results for the different tested sensor locations.

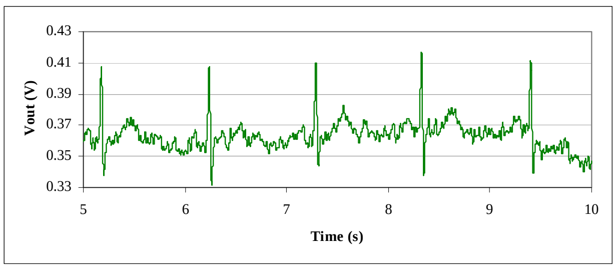

Figure 3. Zone 1 test results.

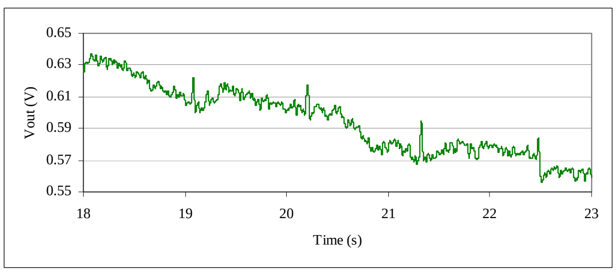

Figure 4. Zone 2 test results.

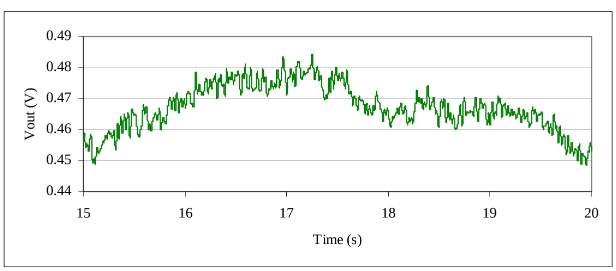

Figure 5. Zone 3 test results.

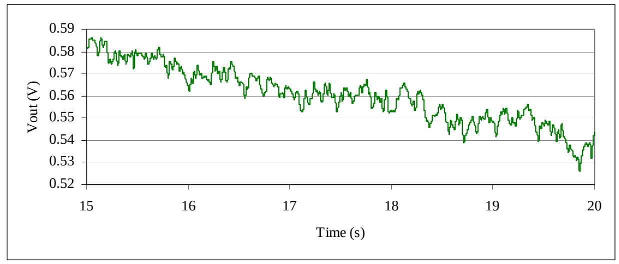

Figure 6. Zone 4 test results.

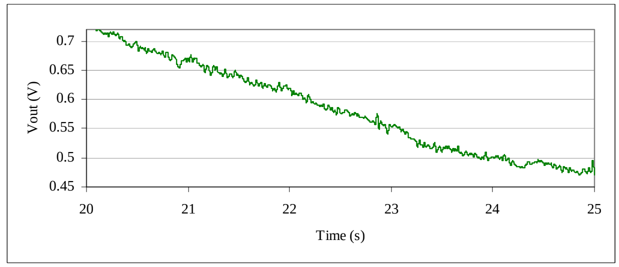

Figure 7. Zone 5 test results.

Plessey's control box has a DRL (Driven Right Leg) input, which was connected to the different parts of the user's skin in the following two graphs.

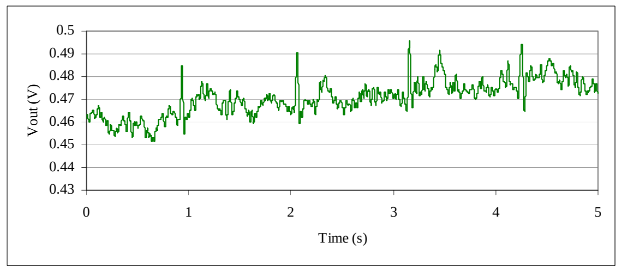

Figure 8. Zone 2 test results with DRL contact in the forehead.

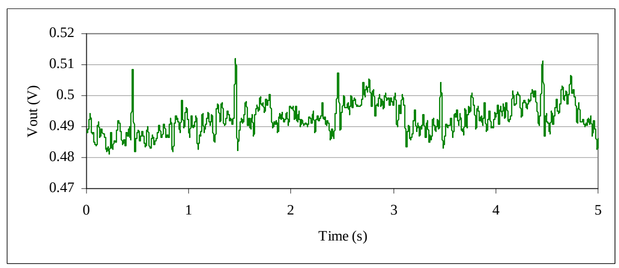

Figure 9. Zone 2 test results with DRL contact in the nape.

As should be expected, the zones closest to the heart, which are in the neck (zones 1 and 2) deliver the highest QRS complexes, whereas the rest of the zones are much noisier.

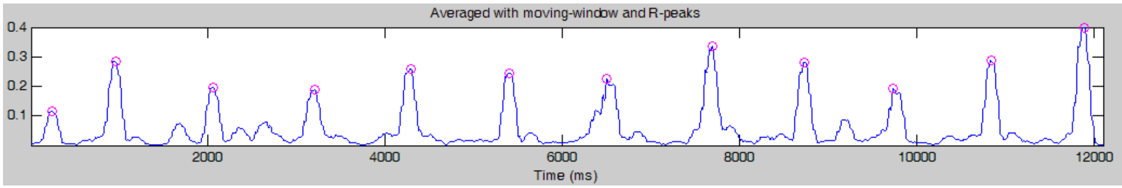

Figure 10. Results from the heart rate algorithm

4.1. Heart rate computation

In order to compute the heart rate, we have tested an algorithm based on a real-time QRS detection method proposed by Pan and Tompkins [10]. First, a band-pass filtering (5-15Hz) is applied. The resulting signal is differentiated in order to find its slope. Then, the result is squared which makes all points positive and emphasises the higher frequencies (related to ECG). Finally, a moving average (window of 30 samples) is computed. The results (after differentiation, square and moving average of the acquired ECG signal) for one data set are plotted in the graph of Figure 10, where the QRS peaks are circled as detected by the algorithm. This algorithm has been tested with a set of different data samples providing accurate results in all cases for static users. However, with a user in movement lots of artefacts appear and the algorithm does not work properly. Further work is required for removing artefacts and computing the heart rate.

5. Conclusions

This paper presents the results of a set of experiments with EPIC sensors for capturing the electrical signal derived from the heart beat. The results show an ECG-like signal which has been used to compute the heart rate through an algorithm. The heart rate can be measured accurately for static users.

Acknowledgements

This work has been developed as part of the project i-VITAL, funded by the European Union's Seventh Framework, Programme "Research for the Benefits of SMEs", under the Grant Agreement no 605427.

References

[1] European Commission website. Road safety information about motorcycles: http://ec.europa.eu/transport/road_safety/specialist/knowledge/vehicle/safety_design_needs/motorcycles_en.htm (Accessed on 27/Aug/2015)

[2] "Road safety in the European Union. Trends, statistics and main challenges," European Commission (Vademecum), March 2015. http://ec.europa.eu/transport/road_safety/pdf/vademecum_2015.pdf (Accessed on 27/Aug/2015)

[3] http://www.plesseysemiconductors.com/epic-plessey-semiconductors.php (Accessed on 27/Aug/2015)

[4] http://cordis.europa.eu/project/rcn/109489_en.html (Accessed on 27/Aug/2015)

[5] EN 16062:2011 Intelligent transport systems — eSafety — eCall high level application requirements (HLAP). 2011

[6] EN 15722:2011, Intelligent transport systems — eSafety — eCall minimum set of data (MSD). 2011

[7] V. Melcher et al, "Smart vital signs and accident monitoring system for motorcyclists embedded in helmets and garments for advanced eCall emergency assistance and health analysis monitoring", 7th International Conference on Applied Human Factors and Ergonomics, 2015

[8] "PS25003 EPIC Evaluation Kit User Guide", Plessey Datasheets (291945.pdf)

[9] "PS25101 EPIC Ultra High Impedance ECG Sensor advanced information", Plessey Datasheets (291346.pdf)

[10] Pan, J., & Tompkins, W. J. (1985). A real-time QRS detection algorithm. Biomedical Engineering, IEEE Transactions on, (3), 230-236

Address for correspondence.

Andrés L. Bleda
CETEM
C/Perales s/n
30510, Yecla, Spain
al.bleda@cetem.es