Sensor-net for Monitoring Vital Parameters of Vehicle Drivers

Gergely Fördős, István Bosznai, Levente Kovács, Balázs Benyó, Zoltán Benyó

Department of Control Engineering and Information Technology,
Faculty of Electrical Engineering and Informatics,
Budapest University of Technology and Economics
Magyar tudósok krt. 2, H-1117 Budapest, Hungary
{fordos, bosznai, lkovacs, bbenyo, benyo}@iit.bme.hu

Abstract: Improving the safety of the traffic is a social interest. Accidents are not only caused by poor technical conditions of the vehicles, but also by tired, indisposed, or bad state-of-minded drivers. The managing of human factors needs the control, recording and monitoring of the most important vital parameters of the driver. The paper presents such a system, which is based on ECG recording and needs no or little cooperation of the driver.

Keywords: phiysiological signal measurement, on-line monitoring, vehicle on-board data collection, ECG, pulseoximetry, bluetooth communication

1 Introduction

In 2005, the Budapest University of Technology and Economics (BUTE) has started a interdisciplinary university-level grant, RET-04/2004, who's aim is to collect a know-how for the automotive industry. Among the 19 subprojects involved, the Control Engineering and Information Technology department's Biomedical Engineering research group coordinates an individual subproject titled RET 5.2 'Human factor in controlled vehicle systems'.

The aim of this subproject is dual: on the one hand to investigate the possibility of creating a sensor-net, which is suitable for recording the driver's vital parameters; on the other hand to develop a human model, which deals with the data collected by the sensors. This paper focuses on the first objective of the project.

Improving the safety of the traffic is a social interest. Accidents are not only caused by poor technical conditions of the vehicles, but also by tired, indisposed, or bad state-of-minded drivers. As a result it can be concluded that the safety and efficiency of today's road traffic over the technical and technological environment is also highly dependent on human behavior. Road users play an essential role in regulating road traffic system. It is possible to influence driver behavior by structural changes in traffic control strategies, road design and vehicle characteristics. Specifications for intelligent driver support systems such as navigation and collision avoidance systems can be developed on the basis of knowledge about traffic participants' reactions.

The managing of human factors needs the control, recording and monitoring of the most important vital parameters of the driver. The most important human factors are the driver characteristics, driver health, mood states and personality factors, driver fatigue, driver decision-making, inattention /distraction and hazard perception.

During the first year of the RET 5.2 project an extensive review of technical literature related to the scope of this research has been carried out. The aim was to explore the stafe-of-art methods – or even ready-to-use systems – which are feasible for monitoring physiological parameters of drivers.

In the elaborated literature review, [1], we have structured the driver observing methods in the following categories:

1. Eye movements, PERCLOS (percentage of eyelid closure), tracking of gaze, EOG (elektro-okulogram);
2. Brain activity, EEG;
3. ECG, HRV (Heart Rate Variation);
4. Facial muscle activity, facial tracking;
5. Lane-related measures (the relative position of the car to the lane border);
6. Heading/lateral acceleration related measures;
7. Combined methods.

We have reviewed the publications in detail, [1], and we have rate them by five aspects:

- Realization: the results were obtained in real conditions or in simulated ones;
- Modeling: was there a model created or only a statistical analyze was made;
- Number of examined physiological parameters;
- Effectiveness of the presented (or created) system;
- Advantages and disadvantages of the article (from our point of view).

From the first three aspects we have summarized the results of the investigated articles and we have concluded the followings:

- It isn't still confirmed that a sensor network is created or researched which monitors the driver physiological parameters (in the sense what we have formulated as our aim for the 5.2 project);
- It is very useful to monitor the drivers physiological parameters from the safe driving point of view;
- It is worthy to start a research activity which investigates the connection between the traffic conditions and drivers physiological parameters.

According to these, two methods has been selected for our project, which involve measurement of two biological signals, [1], [2]:

- Drivers' ECG measurement;
- Oxygen saturation measurements.

The advantages of them, compared to other methods are: no or little cooperation of the driver is needed, they are unobtrusive and compared to image-processing methods require only low bandwidth and less computational power.

Consequently, our conception was to build a system based on signals obtained by the blood-pressure and heart rate measuring devices attached to the driver.

2 The Created Sensor Network

The measurement of the selected biological parameters described above is part of the experimental monitoring system. Figure 1 depicts a sketchy idea of the planned system. Recorded biological signals and supplementary information is sent over a Controller Area Network, which is a standard communication means in the automotive industry, as it is shown on the sketch. A state-of-art vehicle is equipped with one or more independent CAN[1] networks. Electronic components of the engine, transmission, chassis and brake are also connected via CAN. A dedicated network is used to connect components like lights, AC, central locks, seat and mirror adjustment. We can assume that if we want to establish communication between electronic components it is straightforward to use CAN bus; either to utilize one that is already available, or setup a dedicated channel.

[1] Controller Area Network is a broadcast, differential serial bus standard developed by Robert Bosch GmbH, for connecting electronic control units (ECUs).

2.1 The ECG Measurement Device

At the beginning we tried to use existing ECG devices form the market, like the CARD(X)PLORE ECG device from the Meditech Ltd. (which is a combination of holter ECG and ambulatory blood pressure monitor). However, we have realized that this and in generally the ECG devices which are on the market are not capable working on very noisy environments: driver's ECG signals not always could be interpreted (ex sudden movements).

As a result, we have developed a private ECG device to be able to eliminate the mentioned problems, [3], [4].

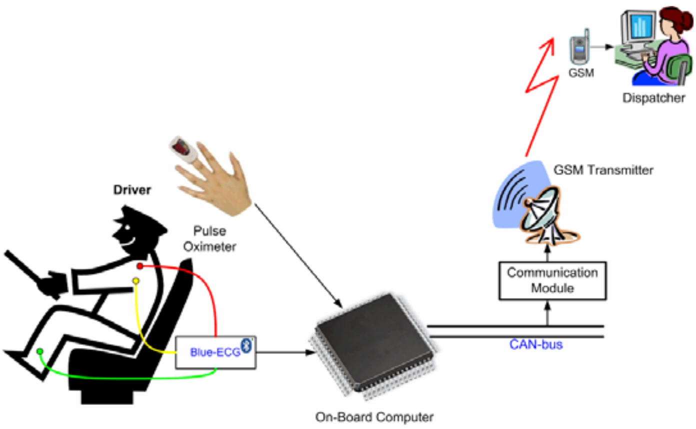

Figure 1

System for on-line monitoring of driver's key vital parameters

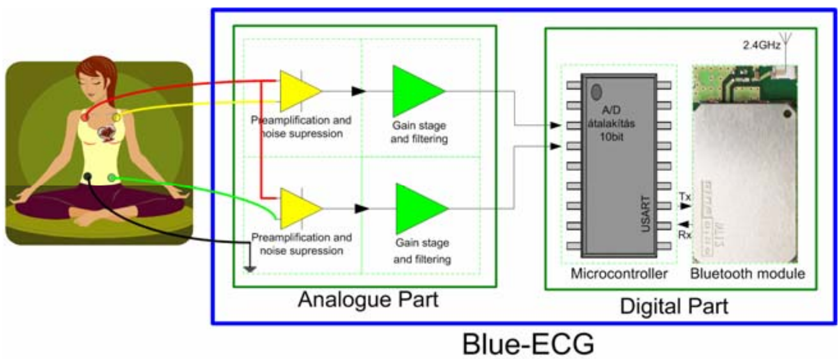

Figure 2

Schematic figure of the developed ECG device

The created system has two parts: one circuit is for amplifying, transforming and transmitting wireless the signal, while the other circuit is to collect and process the data. The schematic figure of the device is presented on Figure 2.

A modern ECG units must have a big common signal rejection ratio. Therefore we have calculated what is the necessary common-mode rejection ratio (CMRR) of the input amplifier, if we suppose that a 0.1 mA current goes through the driver and a maximum 10μV disturbance can be tolerated, while the resistance of the driver is around 1kΩ, [5], [6].

$$
\begin{aligned}
&V_{CM} \approx 0.1mA \cdot 1k\Omega = 100mV \\
&V_Z^{\max} = 10\mu V \\
&CMRR = \frac{V_{CM}}{V_Z^{\max}} = 10000 = 80dB
\end{aligned}
\tag{1}
$$

Our requirements with the amplifier block were:

- At least 80dB CMRR, as mentioned;
- Working on single supply 3.3V;
- Max. 45 mA input current;
- +1.65V average output ECG;
- Working on telemetric principles;
- Even in case of 3m distance a sufficiently quick signal transfer;
- Capable of working continuously, min. 24 hours on battery;
- Small size.

In this way the ECG device can be structured on four main parts and three additional ones.

The main parts are:

- Preamplifier;
- High pass filter and output amplifier;
- Microcontroller;
- Bluetooth transmitter.

The additional parts are:

- Low drop linear stabilizer;
- Power voltage divider;
- High precision reference.

Briefly summarizing, the circuit is amplifying ten times the 1 mV ECG signal, then the high pass filter is cutting the DC component. After this, the output amplifier is amplifying 45 times the 10 mV signal, and the low pass filter is filtering the signals bigger then 106 Hz. The signal which is in this way amplified and filtered, is processed by the microcontroller, which is sampling the signal with 500 Hz, and based on serial protocol transmits it to the Bluetooth device and finally to the receiver. Consequently, the frequency interval is between 0.05 Hz-106 Hz, and the amplification is 450 (Figure 3).

The circuit was developed at the BME-ETT department, [4]. Figure 4 presents this circuit, where for better identification we have labeled the corresponding parts. The Bluetooth device is on the other part of the circuit, so it can't be seen on the figure.

The meaning of the different colors of electrodes used (Figure 6) are:

- Red: Right hand;
- Yellow: Left hand;
- Black: Right leg;
- Green: Left leg;

During the measurements we have used the standard Einthoven lead configuration presented on Figure 6 The electrodes were placed on the body of the driver.

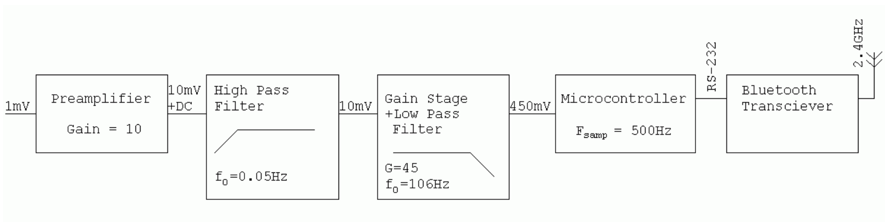

Figure 3

The block diagram of the system

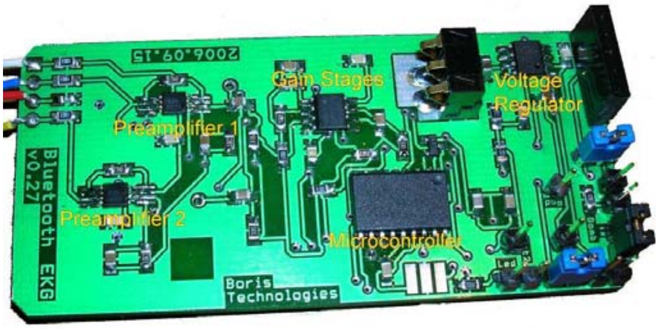

Figure 4

The developed ECG circuit

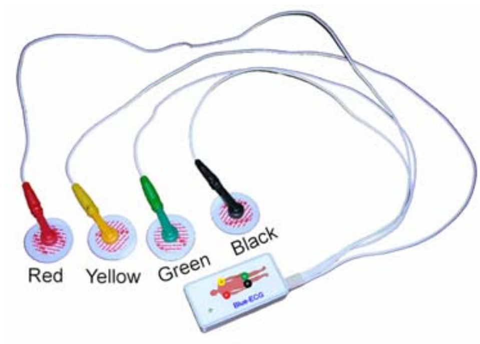

Figure 5

The final BLUE-ECG device

Figure 6

The presentation of the used convention

The two amplifier parts are measuring the signal of Einthoven I and II parts and and calculating the III[2], aVR, aVF and aVL[3] parts.

We have used 3M electrodes, which are so-called second-type electrodes, with metal core closed round with hardly soluble metal acid (like Ag/AgCl). Its advantage is that is not polarizing.

2.2 Brief Description of the Used Pulse Oximeter

The used pulse oximeter is a Nonin Avant 4100 type one (Figure 7) and it was described in the 2007 RET annual report, [3] Pulse oximetry provides estimates of arterial oxyhemoglobin saturation (SaO_2) by utilizing selected wavelengths of light to noninvasively determine the saturation of oxyhemoglobin (SpO_2). There is a tight relationship between oxygen saturation and brain blood perfusion, respiration and heart rate, [7]. The sensor additionally provides heart rate data of 1% relative precision, which can be utilized for heart rate variability analysis – an important measure described later on.

The selected sensor is a portable device and it comes with a finger clip sensor. Measurement data is sent to a computer over Bluetooth wireless protocol, which carries out necessary preprocessing operations. Oxygen saturation and pulse rate data is delivered once per a second. Sensor fault, low perfusion and other artifacts can be detected using the status word which is assigned to each data packet by the sensor.

Although, the pulse oximeter was used in our measurements all the time together with the ECG device, the measured data by it will be used only at the investigation of the second aim of the project (estimating the state of driver's driving capability). As a result in the followings we will restrict only on the ECG measurements.

3 The Procession of the Measurements

As a result, we have concluded that categorizing the driver safety states is necessarily arbitrary. Probably the most plausible category could be if the driver is or not capable to drive the vehicle (of course intermediary categories can be defined). Another division can be: awake, sleepy, insensible (due to an illness), drunk (probably also others).

[2] Leads I, II and III are the so-called limb leads because the subjects of electrocardiography had to literally place their arms and legs in buckets of salt water.

[3] Leads aVR, aVL, and aVF are augmented limb leads. They are derived from the same three electrodes as leads I, II, III.

By our assumption (supported by the big number of the collected and investigated articles) these driver states and the transition between them could be estimated by real-time monitoring of relevant physiological and other (ex. steering wheel angle) parameters.

The measurements were done in a car equipped with the BLUE-ECG device. The investigated traffic situations were:

- Normal urban traffic;
- Urban traffic jam;
- Driving on highway.

Figure 7

Nonin Avant 4100 pulse oximeter

The Einthoven I and II signals were both measured and they were transmitted to a notebook, where the data was processed and recorded. The driving conditions taken into account were:

- Normal driving (straightaway);
- Light truning and shifting;
- Truning

Our aim was to test our ECG device and to see if it is capable of working in these noisy situations. The data was recorded by a software also developed by us in .Net under C#. The main window of the software is presented by Figure 8, [3].

During the measurements, the previous step of starting to use the software is to set the serial port (and if it was necessary the type of the filter). The upper window of the main panel shows on-line the filtered ECG signal, while the lower one the unfiltered one (Figure 8). The filtered signal is needed to get the QRS complex from the ECG singal. The QRS signal represents the heartbeat, this way we could calculate the heartrate, and finally the HRV. A 10-16 Hz band-pass filter was used to filter the noise caused by body movements, the irrelevant parts of the ECG, and the 50 Hz line interference, [8].

The program automatically saves the presented data in a TXT file what is important for us, because the data will be processed and evaluated under MATLAB (for our second aim of the project).

On each measurement we have recorded at least 30 minutes driving in one of the above mentioned driving situations (Figure 9, Figure 10, Figure 11). It can be seen, that even in a sudden movement situation, the recorded ECG signal is interpretable, especially in the situation of determining the R-R[4] distances.

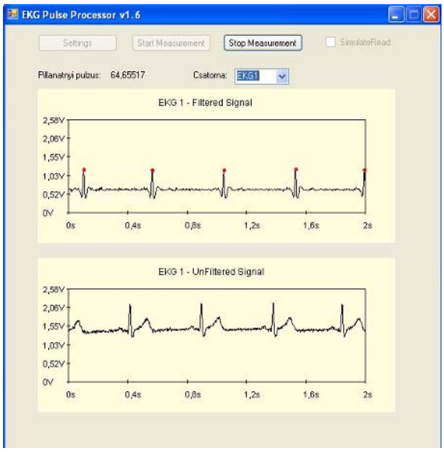

Figure 8

The main window of the ECG Pulse processor software

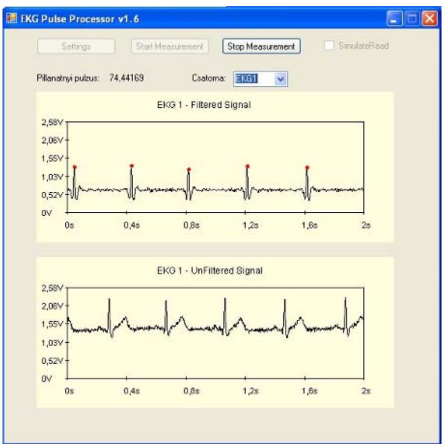

Figure 9

ECG measurements during straightaway driving

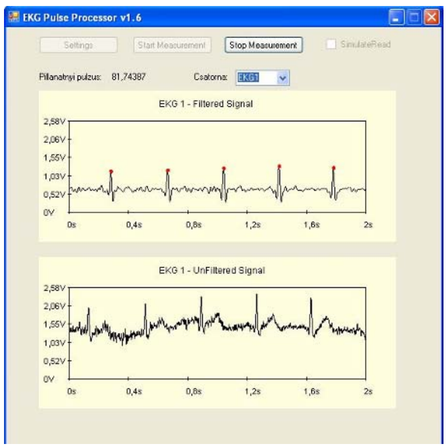

Figure 10

ECG measurements during small movements of the driver in the car

4 R peak: appears, when the heart conrtacts, R-R distance: used to calculate the heart-rate

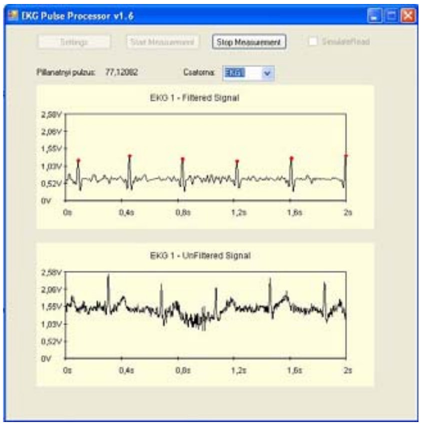

Figure 11

ECG measurements during sudden driving movements

Conclusions and Future Steps

We have realised a sensor-net, capable to record driver's vital parameters in noisy environments. Measurements demonstrated, that the net composed by an ECG device and a pulse oximeter can be efficiently used for our purposes. However, one of our future aims is to improve the sensor net in the sense of a wireless connection and transmission of the measured signals (e.g. no direct electrodes on the driver body).

Regarding the problem of estimating driver's driving capability based on the measured vital parameters and the developed sensor network, we will analyze drivers' stressors. Connected to this, we are planning to develop a classifying algorithm which is able to classify on-line the driving capability.

Finally, based on our results we are planning also to create a hypothetic model describing the interaction between the driver, his car and the surrounding environment. For this we will collaborate with our project's consortium partners: BUTE Department of Transport Automation (Faculty of Transportation Engineering) and BUTE Department of Road Vehicles (Faculty of Transportation Engineering).

Acknowledgement

This work was supported in part by Hungarian National Scientific Research Foundation, Grants No. OTKA T69055, F046726 and by Hungarian National Office for Research and Technology (RET-04/2004).

References

[1] Benyó Z., L. Kovács, L. Török, A. Reiss, B. Benyó: Human Factor in Controlled Vehicle Systems, 2005 annual report, 2005

[2] Benyó Z., L. Kovács, L. Török, A. Reiss, B. Benyó, L. Szilágyi, G. Fördős: Human Factor in Controlled Vehicle Systems, 2006 annual report, 2006

[3] Benyó Z., L. Kovács, G. Fördős, I. Bosznai, B. Benyó: 5.2 Human Factor in Controlled Vehicle Systems, 2007 annual report, 2007

[4] Bosznai I.: Designing and Implementing a Wireless Holter ECG device (in Hungarian), MSc thesis, Budapest University of Technology and Economics, 2007, consultants: Dr. Hunor Sátha, Norbert Stubán

[5] Raimo Sepponen: Biopotential Amplifiers - Medical instrumentation, 2000, http://sel18.hut.fi/166/Bioamplifiers-2005.pdf

[6] Prutchi D., M. Norris: Design and Development of Medical Electronic Instrumentation: A Practical Perspective of the Design, Construction, and Test of Medical Devices, Wiley, 2004

[7] Takatani S, P. W. Cheung, E. A. Ernst: Noninvasive Tissue Reflectance Oximeter: An Instrument for Tissue Hemoglobin Oxygen Saturation in Vivo. Annals of Biomedical Engineering, Vol. 8, pp. 1-15, 1980

[8] Jobbágy Á.: Biomedical Instrumentation I-II (in Hungarian), lecture notes, 1998