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A wearable system developed to monitor people suffering from vasovagal syncope*

Michal Pietrewicz[1], Artur Polinski, Tomasz Kocejko, and Jerzy Wtorek

***Abstract*— A wearable system for monitoring non-invasively signals invaluable when examining person suffering from vasovagal syncope is presented in the paper. Following signals are continuously recorded: electrocardiogram, photopletysmogram, impedance cardiogram and electrodermal resistance.**

I. INTRODUCTION

Syncope is a transient loss of consciousness leading to interruption of awareness of one's surroundings and falls with risk of injury. Syncope has been estimated to occur at least once in about half of all individuals during their life. Underlying mechanism is transient global cerebral hypoperfusion. Decreased cerebral perfusion is common to all causes of syncope. Cessation of a cerebral perfusion for a short time, as 3-5 seconds, could result in syncope. Decreased cerebral perfusion may occur as a result of decreased both cardiac output or systemic vascular resistance. Vasovagal syncope, as in other forms of neurally-mediated reflex syncope, is due to systemic hypotension resulting in a transient period of inadequate cerebral blood flow [1], [2].

Typically, person suffering from episodes of syncopes is examined using a tilt table test approach. Tilt table is used for symptoms reproduction of the syncopal event by changes in body position. The 'gold standard' remains the recording of the cardiac rhythm and if possible, the arterial pressure, during a spontaneous syncopal event [3], [4], [5]. There are many techniques for measuring blood pressure however reliable method for continuous non-invasive measurement has not been developed yet [6], [7]. Thus, it seems that simultaneous monitoring of cardiac output and associated systemic blood pressure during a daily life activity could provide significant information for diagnosing vasovagal syndrome patients [8].

The system was tested for two groups during tilt experiments. Article presents preliminary data for further discussion.

II. SYSTEM ARCHITECTURE

A. Block Diagram

A wearable measuring system dedicated to recording of the 4 biosignals non-invasively has been designed. System is capable of acquiring electrocardiogram - ECG, impedance cardiogram - ICG, photopletysmogram - PPG, and electrodermal resistance - EDR. It allows to estimate blood pressure, cardiac contractility, heart rate, physical activity, and electrodermal activity. In turn, it is expected that feature data extraction from the acquired data may have significant scientific value for helping diagnosing patients with vasovagal syndrome.

A construction of the system is based on STM32F407G-

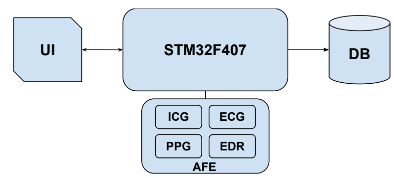

Fig. 1. Block diagram of the developed system, a more detailed description in the text

DISC evaluation board from STMicroelectronics and it is responsible for ADC signal acquisition, DAC sinus wave generation as well as handling user interface and sending/storing acquired data (Fig. 1). The heart of the mainboard is STM32F407VGT6 microcontroller featuring 32-bit ARM'Cortex'-M4 with FPU core, 1-Mbyte Flash memory, 192-Kbyte RAM. It is capable of acquiring 12-bit analog data with the speed of 2.4 MSPS at up to 24 channels. It is also able to generate 12-bit digital signals with its internal digital to analog converter. Nearly real-time operations of the mainboard are because of the maximum 168 MHz frequency of the microcontroller as well as built-in direct memory access (DMA) controller and full speed USB 2.0 interface for sending data.

Second part of the system is the analog front-end board (AFE unit) designed for measuring aforementioned bio-signals, i.e. ECG, ICG, PPG and EDR. Other parts of the system are the user interface (UI unit) which consists of the 0.96 inch, 128x64px OLED display and three user buttons as well as the PostgreSQL database (DB unit) used for data storing.

B. ICG unit

Impedance cardiography (ICG) is a safe, non-invasive method to evaluate a person's hemodynamic status [9], [10]. ICG was measured using a four-electrode technique (Fig. 2). High-frequency sine wave current (20kHz) of a low amplitude is applied between two electrodes placed on the thorax to detect the level of change in resistance of thoracic fluid [11]. Medical standards determine the maximum allowable current that may be safely injected into a patient, starting at 50 μA rms for frequency of tce current below 1 kHz. The

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[1]The Authors are with Faculty of Electronics, Telecommunication and Informatics, Gdansk University of Technology, 80-233 Gdansk, Poland, corresponding Author tomkocej@pg.edu.pl

allowable current doubles for every doubling in frequency, increasing to 1 mA at 100 kHz [12]. Sine wave current is generated using the Howland source by applying sinus wave generated by DAC of mainboard and filtered with 4th order Butterworth bandpass filter (BPF, 20kHz) and then using the low pass filter of Sallan-Key topology (LPF 43.5 kHz). The resulting voltage drop, V, is recorded using two other electrodes also placed on the chest. Then, the acquired signal is amplified by the INA826 instrumentation amplifier from Texas Instruments which provides excellent common-mode rejection as well as low-noise rail-to-rail input/output operation and the extremely low power consumption. After amplification, signal is demodulated within the active demodulator based on LT6621 amplifiers from Linear Technology and then the filtering and amplification stage occurs. The resulted signals are the baseline impedance (Z), derivative impedance signal (dZ/dt) and the respiratory signal (dzResp). As the impedance changes are at the level of about 1 percent, it was compulsory to calibrate the device for every tested person to acquire high precise measurements.

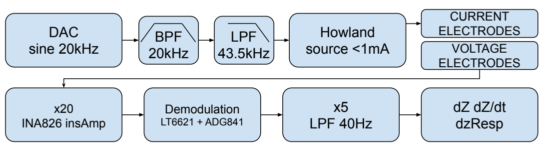

Fig. 2. The block diagram of the ICG unit, a description in the text

C. ECG unit

Electrocardiography is the process of recording the electric activity of the heart over a specific period of time [8], [13]. In the designed device ECG measurement unit utilizes the same set of electrodes as ICG one.
Fig. 3 presents block diagram of the ECG unit. After the instrumental amplification stage, the acquired signal is passed to the 0.3 Hz high-pass filter (HPF) and then to the built-in hardware pacemaker limiter block which is capable of rejecting high amplitude spikes derived from the pacemaker device. Then the gain control unit (GC) as well as set of low-pass filters (LPF) handle the automatic gain for the incoming signal so as to provide the suitable signal amplitude for the analog-to-digital converter of the STM32F407 microcontroller.

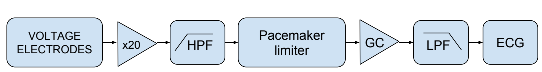

Fig. 3. The block diagram of the ECG unit, a description in the text

D. PPG unit

Photopletysmography is a simple, noninvasive method used to detect volumetric changes in blood in peripheral circulation. It has the advantages of being safe, convenient, inexpensive and all the measurements are acquired at the surface of the skin [6], [7], [14]. Photoplethysmographic unit uses reflectance mode and consists of a simple optical heart rate sensor based on the light source derived from high-intensive green LED and the photodetector based on APDS-9008 light photo sensor as well as amplification and noise cancellation circuitry. It is designed for fast and easy acquisition of reliable pulse readings. The photodiode current corresponds to the minor variations in the intensity of light reflected from the tissue and results in the voltage signal which is forwarded to the amplification and noise rejection circuitry and then to the analog-to-digital converter for further data acquisition. (Fig. 4).

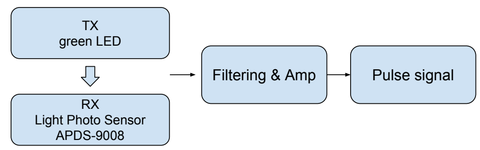

Fig. 4. The block diagram of the PPG unit, a description in the text

E. EDR unit

Electrodermal resistance is a measurement of the electrical resistance of the skin. Dermal resistance is measured using a voltage applied technique thus, electrodermal activity is estimated by only one parameter. Sweating causes changes in the skin conductance, which offers an indication of emotional excitement, because the sweat glands are controlled by the sympathetic nervous system. EDR does not offer a precise indication of the emotions, however, simultaneously with other modalities it may bring interesting data for further analyses [15], [16], [17].
The block diagram of EDR unit is presented in Fig. 5. Constant voltage is applied to the electrodes (a constant voltage technique is utilized) which create the voltage divider with the reference potentiometer. Then, resulted signal is passed to a band pass filter (0.05 Hz to 1 Hz). The high-pass filtering removes the baseline component of the recorded voltage (proportional to average skin resistance) leaving only the changeable component (associated with variational skin resistance) of EDR [16], [18]. Then the signal is amplified and the circuit eventually reflects just the electrodermal events associated with the occurrence of emotional skin response.

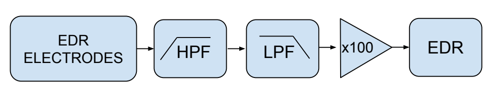

Fig. 5. The block diagram of the EDR unit, a description in the text

F. System overall

Finally, a measuring and data collecting system, consisting of above described subunits, has been developed. It is a portable system supplied by accucell of 18650 type and 2600 mAh @ 3.7 V capacity, and provides real-time ADC measurements with 1 kHz sampling frequency. It is capable of

wireless Bluetooth as well as wired USB data transmission. System is equipped with overcurrent, overvoltage and undervoltage protection as well as electrodes protection circuit. AFE board has been manufactured using SMD technology (Fig. 6). All electronics are enclosed in PLA 3D printed housing and may be attached to a body with nylon straps.
For ICG/ECG measurements the solid gel universal 50 mm AgCl ECG electrodes are used. PPG sensor bases on the 3D printed clip and the EDR sensor uses velcro strips with Ag/AgCl electrodes snap connectors in it. Signals from the electrodes to the acquisition unit are led through the fully shielded cables.

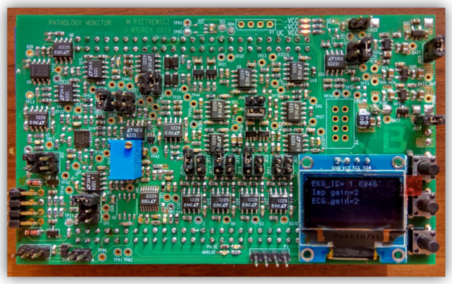

Fig. 6. The analog front-end board

III. RESULTS

The system has been launched and tested on two groups of volunteers consisting of 5 healthy men (average age of 32 years) and 4 healthy women (average age of 28 years). Preliminary measurement data acquired during tilt table test is shown in this section. Detailed procedure of tilt table test has not been developed yet, data was collected during variable intervals of tilt events.

A. ICG unit

ICG unit was based on a four electrode technique in order to reduce influence of electrodes' polarization phenomena on measurement accuracy [9]. Current source has output impedance equal to 1 MΩ and the current amplitude set to 250 μA. A maximal value of the resistance, "seen" between voltage electrodes and accepted by the measurement channel is 120 Ω. Noise characteristics were estimated using a two-port equivalent circuit with mutual resistance of 50 Ω and the sampling frequency of 1 kHz. Noise level was changing regarding the signal gain, however it was not more than 10-12 μV (peak-to-peak). Moreover the Dz/dt signal shift is visible. Nevertheless, the "clean" impedance changes involved by the heart activity were registered (Fig. 7).

B. ECG unit

In spite of using non-standard electrode array configuration the quality of recorded signal is sufficient for a precision determination of characteristic points, e.g. R wave, QRS complex [3]. ECG was recorded (Fig. 8) using the ICG electrodes (the same set of electrodes were used for measurements). Bandpass of the ECG unit was 100 Hz.

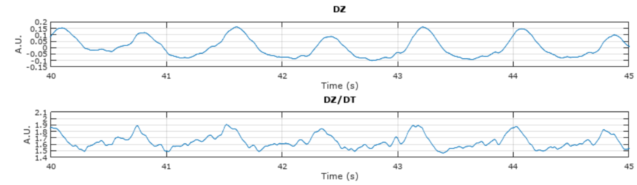

Fig. 7. The impedance cardiographic signal recorded with a four point, linear electrode array attached to the thorax at level of nipples, measurements were performed for man

Noise level, was measured using 5 kΩ resistor simulating impedance of the electrodes. Calculated peak-to-peak voltage noise was below 10 μV.

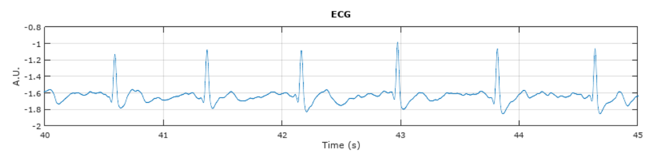

Fig. 8. Electrocardiogram recording using the same electrode array as used for ICG

C. PPG unit

Pulse data has been collected at the index finger of left hand (Fig. 9). Data were acquired with the same, 1 kHz, sampling frequency as other ones. The main features that can be extracted from the PPG signal are the RR intervals and the delay time between the ECG and PPG signal as the signals are recorded simultaneously [6].

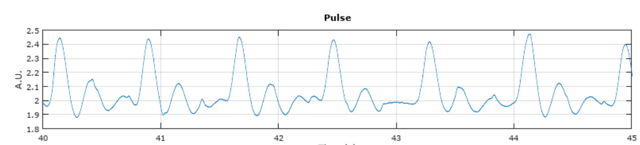

Fig. 9. PPG sample data

D. EDR unit

Electrodermal measurements have been collected from electrodes placed on the middle and ring finger of the left hand. Level of emotional arousal is changing in response to the environment, and the resulted signal therefore is not representative of the type of emotion, but the intensity of it. When the 'emotional' event occured, signal amplitude decreased to slowly increase after the arousal disappears. Sample EDR signal of 100 s duration with few tilt events during its collection has been presented in Fig. 10.

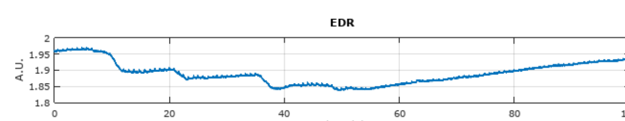

Fig. 10. EDR signal acquisition over the time of 100 s

E. VVS patient test data

System was tested on VVS patient and the title table test has been carried over for about 4 minutes (2 min. horizontal, 2 min. vertical position). Sample data acquired over period of 15 s from person suffering from vasovagal syndrome is presented in Fig. 11.

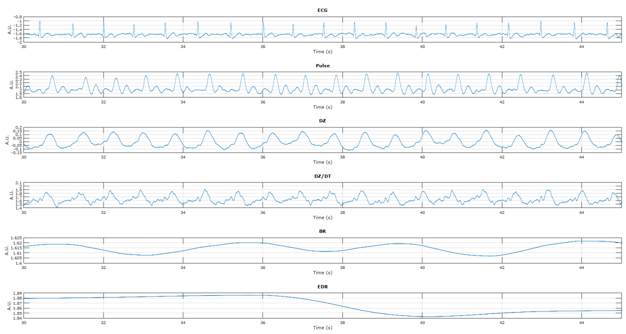

Fig. 11. Data from VVS patient for the period of 15s, from top to bottom: ECG. PPG, IPG, ICG, Respiration, EDR

IV. DISCUSSION

Multi-modal system for examination people suffering from vasovagal syncope has been developed. Basing on ECG, IPG, ICG, PPG and EDA signals, set of calculated parameters (e.g. pulse wave velocity, instantaneous blood pressure changes, CNS activity, etc.), and preliminary studies it seems to be a valuable tool for monitoring patients during a daily activity. Set of the recorded signals allows evaluation of central nervous system. Its evaluation is achieved by continuous monitoring heart rate variability and electrodermal activity. The main advantage of the system is that it is capable of recording many biosignals simultaneously and transfer them to the database in real time. What is more, it is wearable device enclosed in small housing and it may be used for long time, not much affecting daily activities of the examined person. The system is capable of acquisition of well amplified, low-noise data useful for further analyses. Future research is needed to discover coupling between acquired signals which are indicators of cardiorespiratory and sympathetic systems and may have influence on syncopes. It may be valuable to add new sensors (e.g. temperature, pressure, accelerometer) for enhancing capabilities of the system and the signals it is able to measure.

V. CONCLUSIONS

It is possible to develop a compact and portable measuring system potentially useful in collecting valuable data for assesing and diagnosing people with vasovagal syndrome. Future research should explore ways for improving data acquisition methods and address the challenges of validation, implementation and adoption of presented data collection in real clinical settings.

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