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PORTABLE PHOTOPLETHYSMOGRAPHY-BASED DEVICE FOR COMPUTER DIAGNOSTICS

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Abstract: *The photoplethysmographic sensing is a relatively new direction in the data recording area with application in the sphere of computer diagnostics of wide range of industrial diseases. The article describes a new portable device for capturing patient's data by applying a photoplethysmographic method that is suitable for prolonged study and has the advantage of providing better comfort to the observed individuals than conventional (electrocardiographic) methods. Using the device will improve the tracking and control of risk groups of patients suffering from different types of industrial diseases, including cardiovascular diseases. The scientific achievement presented in this article is an algorithm for pre-processing of recorded data, which is then analyzed by applying linear and non-linear mathematical methods. The described application of the photoplethysmographic sensor in the presented portable automatized system consists of a patient data acquisition device and mathematical analysis software. The importance of such system is a possibility of implementation in industrial conditions because of it portability and mobility. The object of the analysis is not only detailed information about the healthy status of the patients (workers) but also create an opportunity to assist in the setting of correct diagnosis, prognosis and prevention of pathology in cardiovascular diseases.*

Key words: *Portable photoplethysmography-based device, Phothoplethysmographic signal, Cardio signal, Discrete sensor, Integrated sensor, Heart Rate Variability*.

1. INTRODUCTION

The development of new models of portable biomedical devices is an important direction in the modern automation of diagnostic activity in medicine. The portable medical devices for computer diagnostics of biosignals are designed for autonomous study of the health status of a wide range of users. According to a report by a world research company [37], they are gaining more demand and distribution and the market for this type of devices is expected to reach $ 20 billion in 2018. The interest in this type of medical devices for automation of diagnostic activities is due to the possibility of continuous monitoring of patients at work and at home, which is the result of the policy of many countries to improve the health of the population.

Biomedical signals are physical expression of the physiological processes occurring in the human body that can be measured and presented in a form convenient for electronic processing [12]. The processing of the biosignals is performed in order to obtain informative data from the point of view of the medical diagnosis or in order to determine the diagnostic parameters of the biosignal [4, 5]. Knowing the parameters and characteristics of the biosignals complements the clinical picture of the disease with objective diagnostic information, which allows to predict the development of the patient's condition. Portable devices have increased diagnostic capabilities compared to stationary means of analysis of biosignals. For their work it is necessary to improve the classical means and algorithms for recording and processing of signals, as well as their work in conditions of free motor activity. The most commonly used biomedical signals in portable devices are: Electrocardiogram (ECG), Photoplethysmogram (PPG), Electroencephalogram (EEG), Functional Magnetic Resonance Imaging (fMRI), etc.

Portable devices for diagnostics of cardiovascular diseases are among the most sought-after medical devices. Applying innovation in this area will lead to a widespread use of this type of device to reduce cardiovascular mortality. In portable ECG devices, signals are usually measured either with electrodes attached to the patient's body or with specific sensors [28]. Both types of electrodes can cause patients discomfort, discomfort, even allergic reactions. ECG signals are influenced by different sources of noise and artifacts [14]. In addition, morphological variations in the ECG signal may affect the recognition of R waves. Due to these disadvantages, the

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PPG signal is introduced as an alternative to ECG and is used in a number of applications, such as a modern, non-invasive technique for recording changes in blood volume in blood vessels [11]. The computer diagnosis of registered PPG signals through the portable device is based on the analysis of the time series consisting of normal intervals between heart pulses [30]. Changes in heart rate intervals are known as heart rate variability (HRV) [7, 9, 10, 25-27, 29].

The **main objectives** of this article are as follows:

1. Presentation of the result of creation a new portable device for registering and processing of PPG signals for cardiovascular status of the patients;
2. Presentation of algorithm for processing of received signals from the device and creating data suitable for mathematical analysis and computer diagnosis of patients' cardiovascular status;
3. Providing experimental results to demonstrate the validity of the received data from the portable device being developed.

2. PORTABLE DEVICE FOR REGISTERING PPG SIGNALS

The traditional way to get heart rate information is through ECG devices. This way of monitoring and diagnosing cardiovascular disease does not provide the necessary flexibility, portability and comfort for users [14]. The use of PPG-based measuring devices is capable of solving these problems [24]. Research in this field has shown that photoplethysmographic technology is suitable for creating individual cardiac devices for long-term observation [1, 2]. PPG based devices are easy to use and can be placed in different places on the human body and allow for the measurement of various parameters that take into account the health of the body such as: pulse, blood pressure, oxygen saturation, etc. [3, 5, 6].

PPG sensor technology uses light properties to detect changes in arterial blood volume in a closed area (fingertip, ear, nose, wrist, etc.)[30, 31]. The principle of action of PPG sensors is to record the changes occurring in the light intensity of reflection or transmission through tissue [1]. These differences reflect changes in circulating human tissue perfusion. PPG sensors can operate in two modes: transmission mode and reflection mode [2].In the reflection method, the light source and the photodetector are placed on the same side of the fabric, while in the transfer method, from two different sides of the fabric [23].

A block diagram of the projected and developed photoplethysmographic device is shown in Fig. 1. The device operates in two modes:

- Transmission mode via an integrated sensor that is external to the device and is a pinch;
- Reflection mode, through a discrete sensor built into the device.

The main elements of the developed devices are the following:

- **Integrated HR / SPO2 sensor** - The sensor (Fig.2) has a clip and consists of two main elements (1 and 2) which are connected together by means of axis 3 and are opened and closed by means of the spring 4. The integrated circuit (Fig. 3) is a complete solution for measuring heart rate and oxygen content in the blood using a photoplethysmographic method [32]. This circuit is chosen because of its small size and low power consumption. The main components of the circuit are:
  - Red and infrared LEDs (item 1 on Fig. 2). They provide the necessary light for pulse and oxygen content measurements. These LEDs work at different wavelengths. The red LED works at 660 nm wavelength, and the infrared LED is 880 nm. These two wavelengths are selected because the deoxygenated hemoglobin has a higher absorption at about 660 nm and the oxygen hemoglobin 880 nm. The photosensor (element 2 of Fig. 2) reports the strength of the red and / or infrared LEDs. The current through them is controlled by PWM (Pulse Width Modulator), which reduces energy consumption.
  - Ambient Light Cancellation - a system for reducing the impact of side light.
  - Built-in temperature sensor for temperature reading because it affects the wavelength of both LEDs.
  - Analogue-to-digital converters for digital signal digitization from photocopiers.
  - Digital Filtering Module.
  - Interface module for connection with microcontroller via USB cable.
- **Discrete HR / SPO2 sensor -** For experimental purposes, the device also provides the possibility of using a simple red LED [36].
- **The microcontroller is ARM, Cortex-M4** having a maximum operating frequency of 120MHz (Microchip, ATSAM4S16C) [35]. The use of a relatively powerful microcontroller will allow the addition of additional functionality without a substantial change to the basic scheme. It performs the following tasks:
  - Managing and receiving sensor data;
  - Connecting to a PC;
  - Record the received data in non-volatile memory.

  Device tasks is managed by real time operating system NUTTX [22].
- **Power -** The power supply unit (Fig. 4) contains two main components:
  - Module for charging the battery to provide the required voltage and current [38].
  - Pulse converter (DC-DC converter) to create a voltage of 3.3 V to power the entire electronic part of the device. A buck-boost converter is used to make better use of the battery.

When using a USB cable, the built-in power supply is automatically charged.

- **Interface for communication with external devices:**
  - USB interface;
  - Wireless Interface - WiFi / BT.

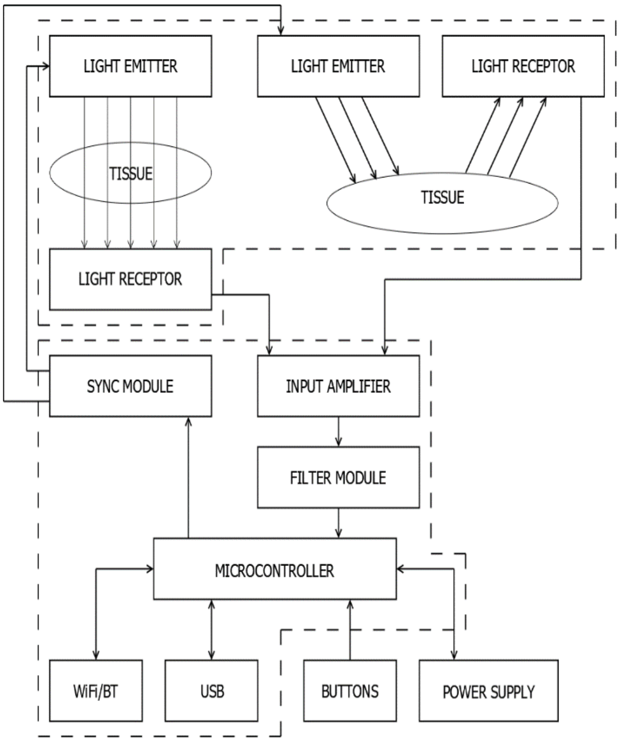

Fig. 1. Block diagram of the photoplethysmograph device

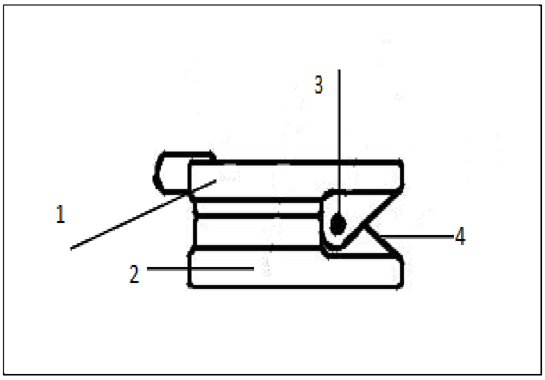

Fig. 2. A schematic diagram of an integrated sensor, type pinch

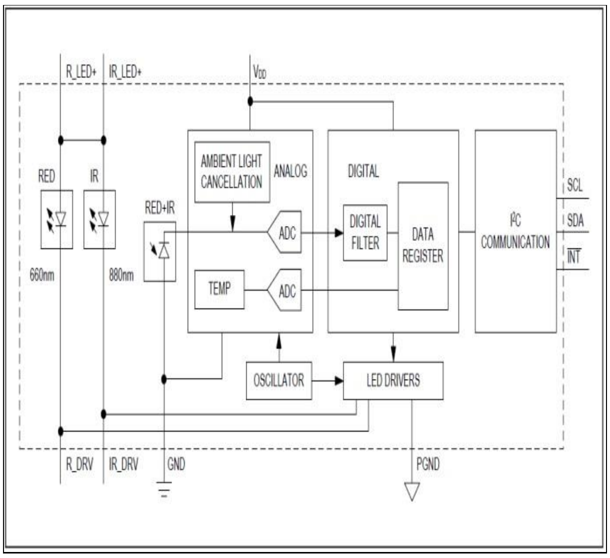

Fig. 3. Integrated HR/SPO2 sensor

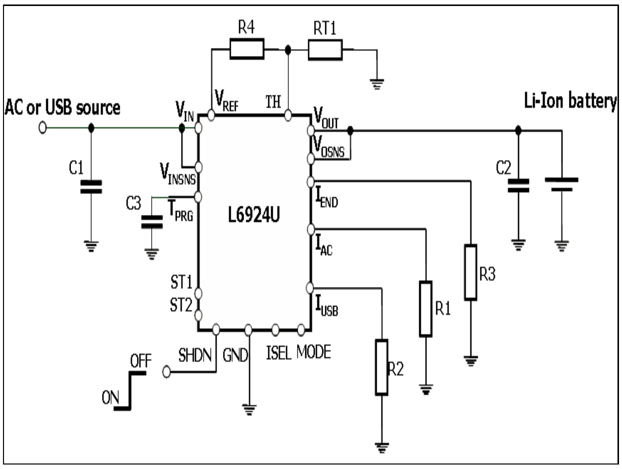

Fig. 4. Power supply

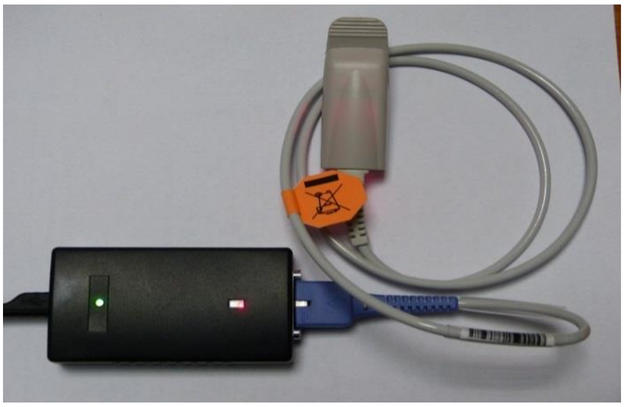

Fig. 5. PPG device

- **Control buttons** - The following buttons are provided in the machine to control its operation:
  - Sensor selection button: discrete or integrated;
  - Button to mark the beginning and end of the recording;
  - Wireless communication on/off button. By default, the device information is transmitted for processing and analysis to the PC via the USB interface.

The finished view of the device is shown in Fig.5.

The advantages of the developed device based on the photoplethysmographic method are the following:

- High sensitivity;
- Ability to work with two types of sensors: discrete as pinch and integrated;
- Portable dimensions 96 mm/52 mm/25 mm and low weight: 85 grams;
- Easy to use;
- Ability to firmly position the finger of the hand.

The disadvantages of the device are the following:

- Influence of different artefacts as a result of the movement of the studied individual;
- Dependence on the condition of the surface of the individual's biological tissue.

3. ALGORITHM FOR PROCESSING OF PPG SIGNALS

The algorithm for processing PPG signals includes the following main activities:

- pulse wave detection [9, 19];
- pre-filtration [17, 18];
- removing noise;
- determination of the P peaks;
- determination of RF intervals;
- removal of artefacts;
- creating normalized PHP intervals.

Various algorithms exist for the detection of maximum amplitude variations in the photoplethysmographic signal [19, 20, 21].

The main steps of the algorithm are as follows:

Step 1. Receiving input data (signals) from:

- Integrated sensor in digital form;
- Discrete sensor after analog-to-digital conversion.

Step 2. Pre-filtration involves removing the constant component of the signal. The signal received by the sensors contains two components: constant and variable. For the determination of the P vertices, only the variable part is needed. A filter is programmatically implemented based on the information from [33, 34].

Step 3. Removing the noise from the input data by applying an averaging filter.

Step 4. Removing individual large deviations in the input data by applying a median filter.

Step 5. Removing the high frequency components from the input signal through a low pass filter. If the maximum heart rate is 220 beats per minute, heart rate is about 3.7Hz. Any higher frequency signal should be suppressed to prevent further processing.

Step 6. Investigation the slope of the signal curve by checking for increment:

- if the value obtained is greater than the previous one, the maximum value is updated and the process continues to process the next received data;
- if the received value is less than the previous one, the current position is memorized in an internal buffer of about 0.5 - 0.6 seconds.

Step 7. Perform a second check to see if the maximum is wrong by re-searching the last 0.5 second data to determine the exact position of the P peak.

Step 8. Determination of PP intervals is shown on Fig. 7.

Step 9. In the filtering process, it is necessary to take into account the following: the frequencies resulting from the influence of artifacts caused by the displacement of the individual are usually at frequencies less than 0.1 Hz [15], the range of the respiratory frequencies is usually from 0.15 Hz to 0.4 Hz and the heart rate is about 1 Hz [15]. Filtering with a bandpass filter (starting and ending frequency: 0.5Hz and 4Hz) for bandwidth reduction of PPG data. Object of removing are the artefacts and FP intervals that are 25% shorter and 25% longer than the median of the previous five FP intervals, as well as FP intervals shorter than 333 msec, longer than 2 s.

Step 10. If no more processing data is available, write a data in the local memory or send it for further processing that includes implementation of actual mathematical methods - linear (time and frequency domain analysis) and non-linear (Poincare, Detrended Fluctuation Analyses - DFA, etc.) for which are developed algorithms [16].

Step 11. Printing the results of the diagnostics.

A Microsoft Visual C ++ software program has been developed to process PPG signals from the portable computerized device, based on the photoplethysmographic sensor.

Fig. 6 shows the pulse wave produced by the PPG device.

The pulse wave consists of 2 peaks: the first peak corresponds to the systolic wave, the second peak corresponds to the reflected wave. The duration and frequency of the pulse wave depends on the work of the heart, and the shape and size of its peaks depends on the condition of the blood vessels.

Fig. 7 shows the PP ranges obtained by the algorithm described above for processing the PPG signal of a young subject (20 years).

4. EXPERIMENTAL RESULTS

A study of the performance of the portable PPG device was carried out by comparison with a second reference method - an electrocardiogram. Synchronic finger pulse wave signal and electrocardiogram were recorded (Fig. 8). The results show a complete correlation between the ECG signal and the photoplethysmogram of the subject under study. The experimental study of the proposed device indicates that it is applicable for recording pulse waves, which can then be analyzed by dedicated software for computer diagnostics.

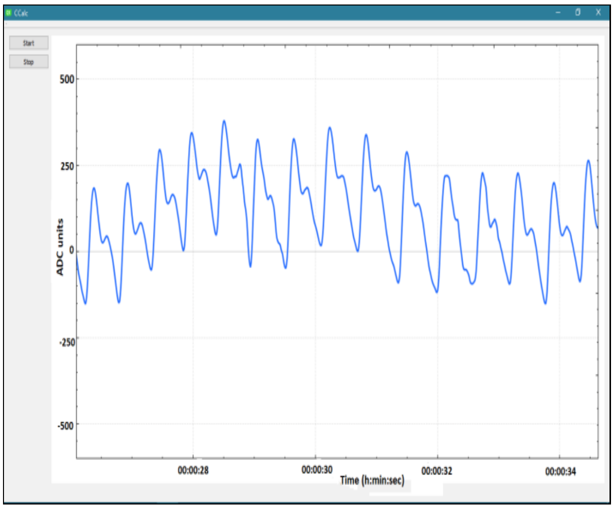

Fig. 6. PPG signal of a young subject

5. CONCLUSIONS

The subject of the present study is the description of the created new portable device for registering PPG signals and new algorithm for processing the received signals in a suitable form for mathematical analysis and computer diagnostics of the cardiovascular status of the studied individuals. The phothoplethysmography, as a diagnostically method, is used for objective assessment of cardiovascular status of the patients. From the experimental research, done on the operation of the.

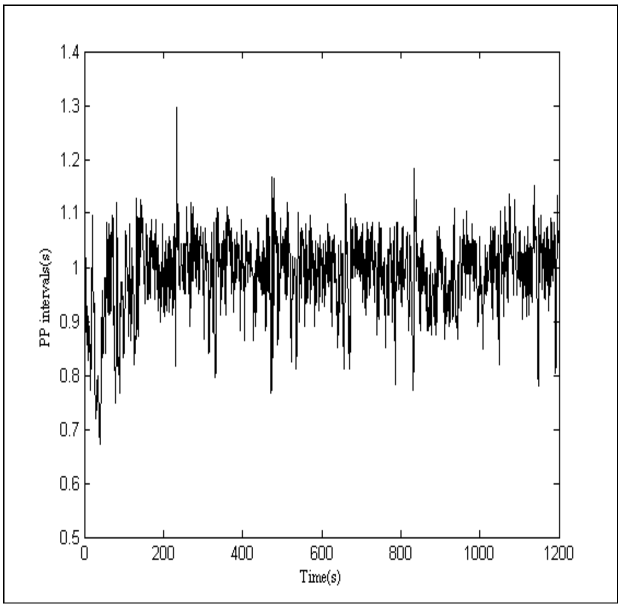

Fig. 7. PP interval series of a young subject

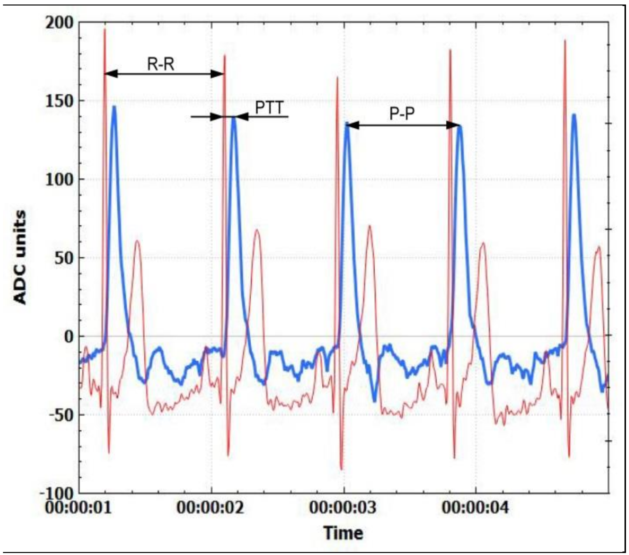

Fig. 8. Synchronically recorded pulse waves in the fingertip and ECG area

portable PPG device by comparison with a second referenced method - an electrocardiogram, it follows that the device is fully applicable for detection and recording pulse waves and data for health status of the patients in industrial conditions. The registered PPG signals, through the proposed new portable photoplethysmography-based device, are processed and analyzed by a software system for automatic diagnostics. Based on this analysis, a parametric and graphical assessment of the patient's health status can be made

The main benefits of the portable device for patients are as follows:

- **mobility -** PPG signals are recorded while the patient is working, traveling, sporting, resting, as well as in extreme situations;
- **security -** if necessary, 24-hour monitoring is possible, when a patient's results are recorded. A short message (SMS) for the current status can be sent by the patient or relatives to his / her personal physician (GP) or to the emergency medical center;
- **prevention** - determination the current health status before appearing the serious health problem;
- **diagnostics** - continuous monitoring of patients gives a possiblity for assistance in process of determination of correct diagnosis;
- **economy -** it is possible to avoid unnecessary waste of time for additional medical research, as well as hospital stay;
- **trust in the health system** - the relationship between the doctor and the patient is strengthened;
- **social effect** of improving the care of industrial enterprises for their employees.

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