PHOTOPLETHYSMOGRAPHIC DETECTOR FOR PERIPHERAL PULSE REGISTRATION

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In this paper a low power photoplethysmograph for heart rate detection by the amplitude demodulation of the reflected from the skin and tissue light is proposed and described. The optical sensor consists from six infrared photoreceivers placed in a circle around one infrared led. The use of only one emitter in switch mode and synchronous detection of the received signal defines the achieved low power consumption. The device can be used for fast heart rate registration, for example in emergency cases or in addition to existing defibrillators and/or monitoring systems.

Keywords: photoplethtysmograph, photo-transducer, infrared pulse detector

1. INTRODUCTION

The peripheral pulse registration, often called photoplethysmography, is based on small changes in the tissue optical properties due to blood circulation. In the beginning, this method was used in addition to the ECG signals monitoring systems. The principle of operation is based on registration of a useful signal, corresponding to the heart rate activity, by using two possible methods: (i) transmissive method - when the light passes through the tissues and (ii) reflective method - when the light is reflected by the tissues. The two mentioned principles are investigated in details by Nijboer [1]. In case of using the reflective light, the distance between the light emitter and the light receiver is relatively short, consisted only by soft tissues, in contrast to the case of transmissive light, when the distance is longer and often the light path passes through solid matter, e.g. bones. Therefore, the reflective method could use light emitter with relatively smaller intensity, which defines the higher efficiency of the schematic.

The photoelectronic transducers with analogous operation are used widely in the pulse oximetry [2, 3, 4]. It is a noninvasive, widely-applied method for measurement or long-term monitoring of the oxygen saturation, by taking of a photopletysmographic signal from a finger, the ear, the forehead or some other places. As a principle, the transmissive and the reflective measurements with two light wavelengths, in the red and in the infrared spectrum, are used. The physical and the technical similarity between the photoplethysmography and the pulseoximetry permit the comparison of the results, which are obtained by these two methods.

One of the frequently used phototransducer designs consists of several light-emitting diodes, which are placed around one photoreceiver [5, 6]. Initially, the red leds were used, but recently the infrared leds were preferred in combination with an infrared filter at the receiving side. Thus the ambient light influence is rejected [7, 8].

The most comfortable location for application of the photoplethysmographic sensor is a finger of the hand. Some investigations are orientated towards the development of methods for decrease of possible motion disturbances, which include different mechanical decisions, for example design of finger-ring plethysmographic sensor, as well as different methods for signal processing [9].

In many practical cases, the acquisition of photopletysmographic signal from the finger is impossible, e.g. in cases of inaccessible position of the limb or interrupted blood circulation. In these critical situations, the few possible positions for placement of the phototransducer remain the chest, the forehead or the face. Our investigations showed that the forehead is practically the most comfortable place, which is moreover associated with the presence of high quality signal.

2. PRINCIPLE OF OPERATION AND PRACTICAL REALIZATION

The transmitted light is reflected or absorbed mainly from the tissues, the bones, the venous blood, the arterial blood and the arterial blood pulsation. This is shown by the illustration of a photopletysmographic signal in fig.1. It is the upper variable AC component, which represents only a small portion of the total light, which contains information about the heart rate activity.

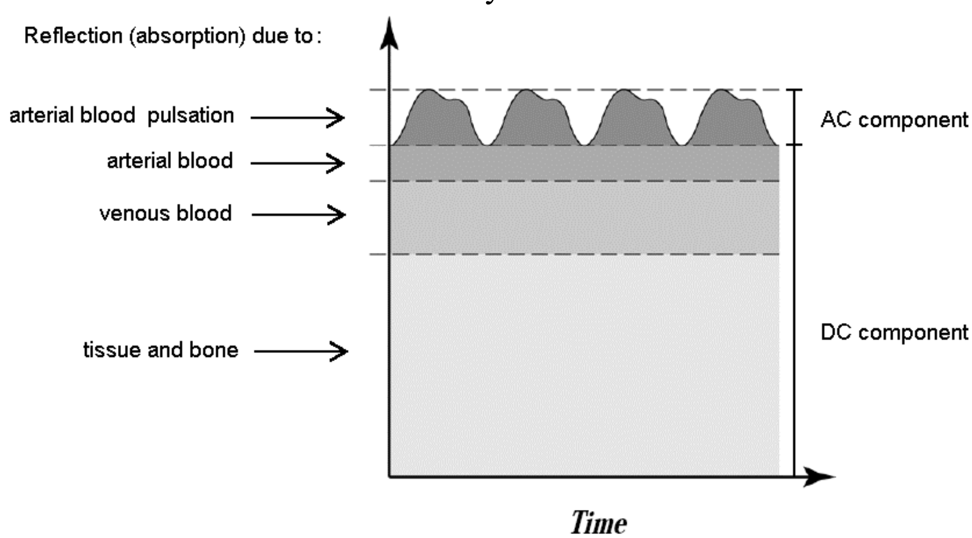

Fig.1. The light reflection or absorption through the body structures

The ratio of the variable AC component to the constant DC component (level of modulation) varies in a wide range from 0.01% to 1%, depending on the position and the contact pressure of the phototransducer in respect the body.

The infrared photodiodes HSDL-5400 and infrared led HSDL-4420 manufactured by Agilent Technologies were selected for the experimental study. They have a small input capacitance (HSDL-5400 – 5pF and HSDL-4420 – 50pF), high speed and SMD assembly.

We considered that the reflective phototransducer had both lower power consumption and easier for manipulation/comfortable construction compared to the transmissive phototransducer, therefore we decided to continue the experimental study with the reflective phototransducer. The experiments were performed with two configurations of the reflective phototransducer: (i) one infrared led with few photodiodes around it, and (ii) one photodiode with few infrared leds around it. No essential differences of the stability and the level of modulation between the two configurations were detected. Therefore, in order to minimize the power consumption, we decided to use the first configuration of the photosensor, which was constructed by one infrared led and few photodiodes around it. The photosensor design is shown in fig.2.

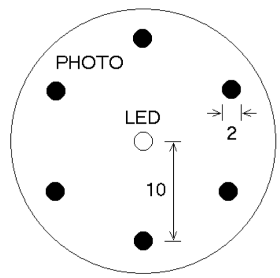

Fig.2. Photosensor design

The optimal experimental results were obtained when the distance between the infrared led and the photodiodes is about 10 mm. The amplitude of the useful signal strongly decreases when the distance between the led and the photodiodes becomes shorter due to the direct illumination. However, lengthening of the distance makes the photosensor uncomfortable.

The experiments were performed with two disks, where the infrared led and the photodiodes were mounted: (i) with black surface and (ii) with white surface. The experimental results showed that the level of modulation is independent of the background color, but the detected signal with the white disk surface has about twice higher amplitude. Therefore, we decided to use in the future experiments the disk with the white frontal color. In case of good contact between the disk and the body surface (forehead), we found that practically the ambient light does not influence the signal due to the integrated into the photodiodes infrared filter.

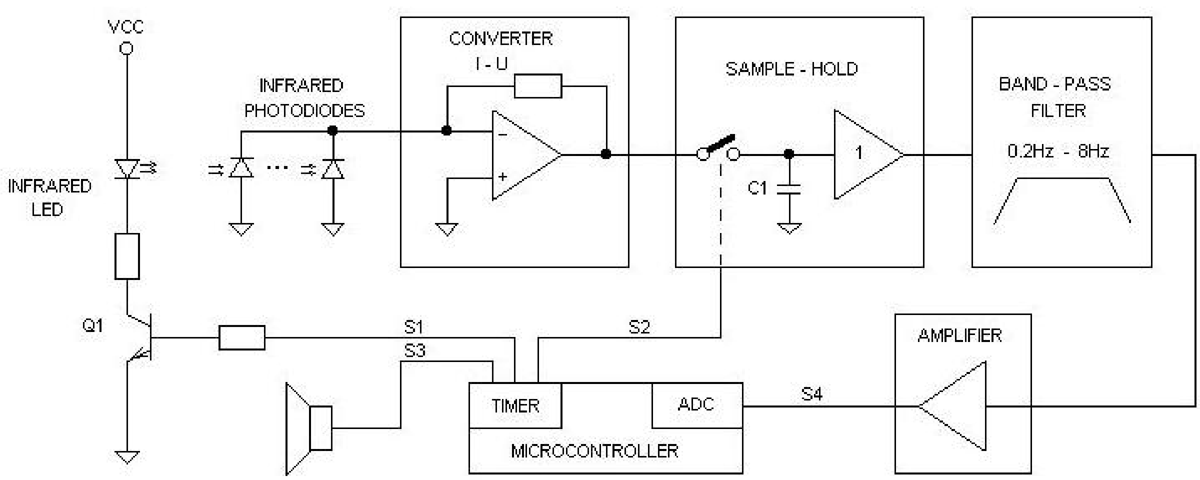

Fig.3. The photoplethtysmograph block diagram

The photoplethysmograph block scheme is shown in fig.3. The led current is relatively big – 65mA, chosen to provide good signal-to-noise ratio. The pulsed led current is turned on/off by the transistor Q1, which is controlled with the microcontroller-generated signal pulse S1. The signal S1 has pulse-width of 60µs and period of 10ms. When the led is turned on, the sample-hold circuit is activated by the signal S2 and then the input signal is sampled. The hold mode is started for a short time interval, just before the led is switched off. The signals S1 and S2 are shown in fig.4.

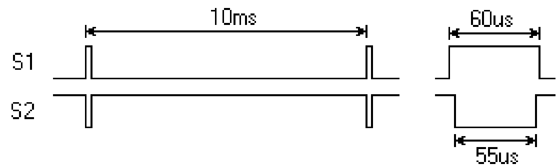

Fig.4. Time diagram of the signals S1 and S2

As a result from the synchronous pulsed control of the led current and the sample-hold circuit, the average value of the consumed current by the led (I_{AVG}) is decreased, depending on the pulses duty cycle:

$$I_{AVG} = \frac{t_p}{T} \cdot I_{LED} = \frac{60us}{10ms} \cdot 65mA = 0.39mA$$

When the led is turned off, the capturing of the voltage in time is realized through the capacitor C1. After buffering, the signal is band-pass filtered in the frequency band from 0.2Hz (1st order) to 8Hz (3th order). Thus, its DC value and the remaining high frequency components, which are introduced during the analog sampling, are totally removed. After amplification of the useful signal of about 150 times, it is converted to digital data by the ADC of the system microcontroller (PIC12F675) in every 10ms (sampling frequency of 100 Hz). The heart rate is detected with digital signal processing procedure, and a synchronous acoustic signal (beep) is generated. The microcontroller operates with integrated RC oscillator (4MHz), with power consumption of about 0.6mA at 3V.

3. EXPERIMENTAL RESULTS AND CONCLUSION

The photoplethysmograph operation to register the pulse on the forehead is illustrated in fig.5. The first trace represents the filtered signal, which is applied to the ADC input (signal S4 of fig.3). The second trace corresponds to the detected heart rate, represented by the signal S3 (of fig.3), which is generated to control the buzzer for sound signalization.

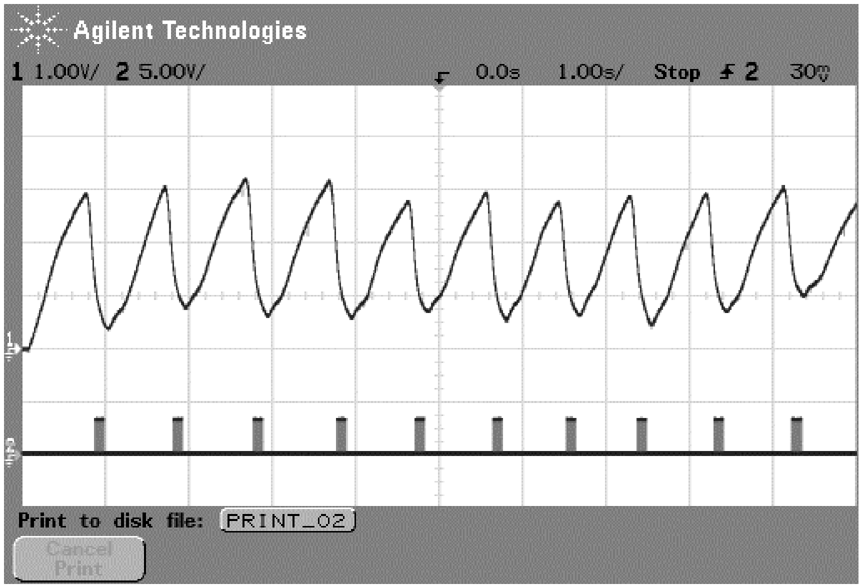

Fig.5. The forehead registered photoplethysmographic signal (channel I) and the detected heart rate (channel II)

The external view of the device is shown in fig.6. It is attached and hold to the forehead by an elastic band with adjustment length. The device is supplied by one 3V Lithium battery type CR2032 with 200mA/h capacity. The low power consumption (about 1mA) from the battery ensures more than 5 days continuous work.

Fig.6. External view of the developed photoplethysmograph

The experiments showed that the heart rate could be effectively detected from different places on the body, with good blood supply, for example the flat of the hand, the elbow joint, the neck, the cheek and the forehead. However, the minimal motion artifacts combined with easy and comfortable placement of the photopletysmographic device are assured only in the position in the forehead.

The registration of good and undisturbed photopletysmographic signal with the developed device becomes a very useful technique for fast heart rate detection, which is applicable in emergency situations and/or as an additional module to defibrillators and monitoring systems.

4. REFERENCES

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