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MULTI-SPECTRAL OPTOELECTRONIC DEVICE FOR SKIN MICROCIRCULATION ANALYSIS

L. Asare, E. Kviesis-Kipge, M. Ozols, J. Spigulis, and R. Erts

Institute of Atomic Physics and Spectroscopy, University of Latvia, Raina 19, LV-1586 Riga, Latvia
E-mail: lasma.asare@yahoo.com

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The developed optical fiber laser diode biosensor comprises one multi-wavelength laser diode (405, 660 and 780 nm) and a single photodiode with multi-channel signal output processing and a built-in Li-ion accumulator. Special software was created for visualisation and measuring of multi-spectral photoplethysmography signals. The prototype device was tested on 11 healthy subjects.

Keywords: photoplethysmography, biosensor, multi-wavelength

PACS: 42.62.Be, 47.63.Jd, 85.60.Jb, 87.19.U-

1. Introduction

Photoplethysmography (PPG) is a simple and low-cost optical technique that can be used to detect blood volume changes in the micro vascular bed of the tissue. It is often used for non-invasive measurements on the skin surface [1]. Reflection photoplethysmography detects the tissue backscattered radiation with time resolution [2]. The PPG signal consists of AC and DC components. The AC component reflects the vascular pulsations, and the DC component represents the light scattered from relatively steady blood volume and tissue layers, which are the components without a pulsatile signal [3].

The multi-spectral photoplethysmography (MS-PPG) biosensor is intended for analysis of peripheral blood volume pulsations at different vascular depths. The light penetration depth into skin varies depending on wavelength (Fig. 1).

Consequently, a parallel analysis of PPG signals at different wavelengths might help to assess skin damages and pathologies at various tissue depths.

This study continues our previous research [5] with the aim to understand more deeply the pulse shape changes at different tissue depths.

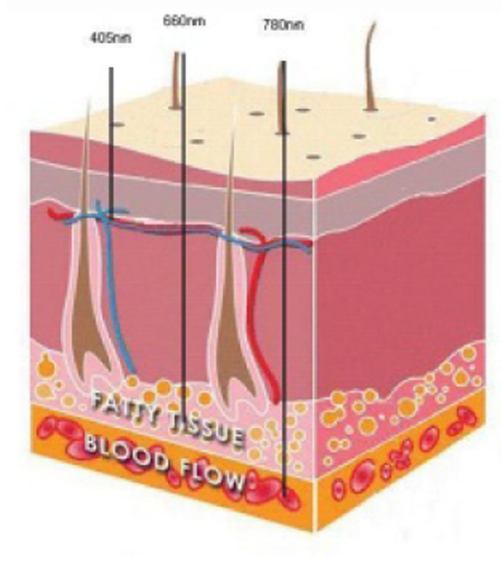

Fig. 1. Depth of penetration into skin for different wavelengths [4].

2. Methods

2.1. Instrumentation

Our set-up consists of a 3-wavelength (405, 660 and 780 nm) laser diode, PPG contact probe, a central system control unit, and a Li-ion accumulator.

The design of the scheme is based on the measurement of the photodiode discharge time using a 32-bit timer which is built into the microcontroller [6]. The power supply voltage is stabilised by means of a built-in current regulator. The USB-COM connection is used for transmission of the captured data from device to computer. Red and infrared (IR) wavelength radiation output can be changed in the interval from 90 to 280 μW, while blue radiation output is constant. The device does not include an analogue amplifier and filters thanks to the new digital PPG measuring approach [7]. The signals are acquired with respect to the measuring photodiode discharge time – a longer discharge corresponds to a higher intensity of back-scattered radiation. The biosensor operates in a contact reflection mode, with simultaneous sequential recording of PPG signals at each wavelength (Fig. 2).

The contact sensor head is connected to the device by a 1 metre long cable which allows easy measuring of fingertips of volunteers. An especially polished 5 mm long optical fiber fragment is inserted between the laser diode and sensor output to avoid direct contact with the skin surface. The optical fiber diameter is 2 mm. The sensor head measuring area is 5 mm^2. The dimensions of the prototype equipment are 140 × 90 × 35 mm and weight is 250 g; it is battery-powered and can operate up to 10 hours without recharging. The device is connected to a laptop; special software allows recording the photoplethysmographic signals online during the measurements.

As an alternative, another MS-PPG biosensor based on LEDs was designed (Fig. 3). It comprises one 3-wavelength RGB (red-green-blue) LED, IR LED, and a single photodiode with multi-channel signal output processing; special software was created for visualisation and measuring the MS-PPG signals. The RGB LED is emitting three wavelengths separately one after another (630, 530 and 465 nm). The IR LED is emitting the wavelength of 870 nm. The contact sensor head is connected to the device by a 2 metre long cable which allows reaching any place

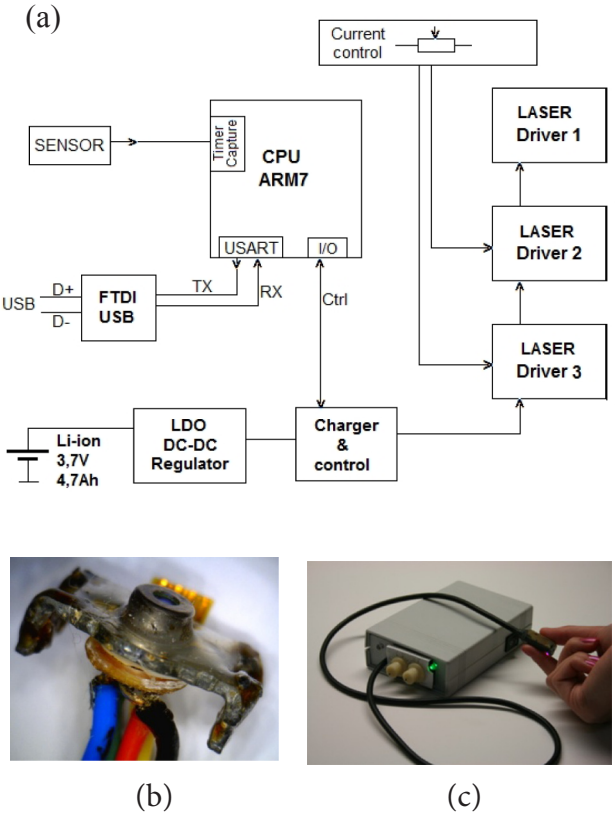

Fig. 2. (a) Block diagram of the laser diode biosensor device. (b) View of the laser diode from the side. (c) The laser diode prototype biosensor device.

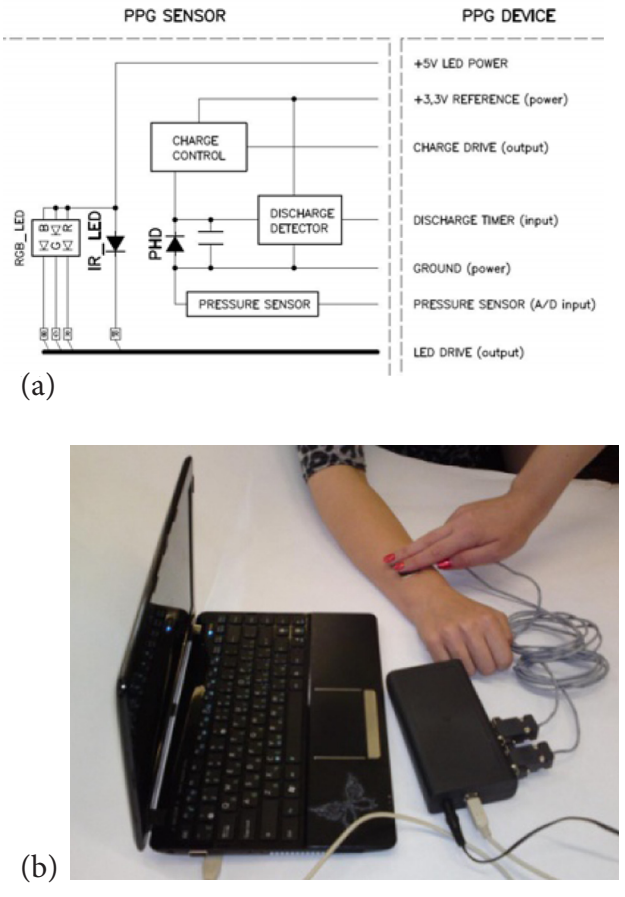

Fig. 3. (a) Block diagram of the LED biosensor device. (b) Experimental set-up of the LED biosensor device.

of the body of the volunteer to measure MS-PPG signals. The measuring area for the sensor head is 5 mm^2. Dimensions of the prototype equipment are 148 × 80 × 34 mm and weight is 105 g; it is AC adapter powered. This prototype has higher sensitivity and can be applied to various places of the body, with potential to detect differences between PPG signals of healthy and unhealthy skin at four wavelengths.

2.2. Experimental protocol

The multi-spectral photoplethysmography recordings of a laser diode prototype were obtained from 11 healthy male volunteers. The age of volunteers was between 22 and 40. Measurements were performed in a laboratory (a well-ventilated room under reasonable constant temperature which was typically 20 °C). Each volunteer was asked to relax and sit on a chair. The MS-PPG recording time was between 90 and 120 s.

The LED prototype was also tested in a laboratory. Each volunteer was asked to lie down on a bed and calm down for 5 minutes. Before each measurement blood pressure was measured with a commercial device. The MS-PPG recording time was between 60 and 80 s.

In vivo measurements were performed with permission of LU EKMI Research Ethics Commission.

2.3. Signal processing

At the first step, experimental data were analysed with the custom designed *MathLab* software. The program calculates the mean single-period photoplethysmography signals (SPPPG), max ejection velocity, stiffness index (SI) and reflection index (RI). For obtaining correct parameters it is needed to write the volunteer's correct height in centimetres in the program window before calculating hemodynamic parameters. At the second step, experimental data were analysed with the *Origin 8.0* data analysis and graphing software. To check repeatability of measurements the mean of the mean value for each wavelength was calculated.

3. Test results

Some results of our laboratory tests of a 3-wavelength laser diode prototype (Fig. 4(a, b)) are described in our earlier paper [8].

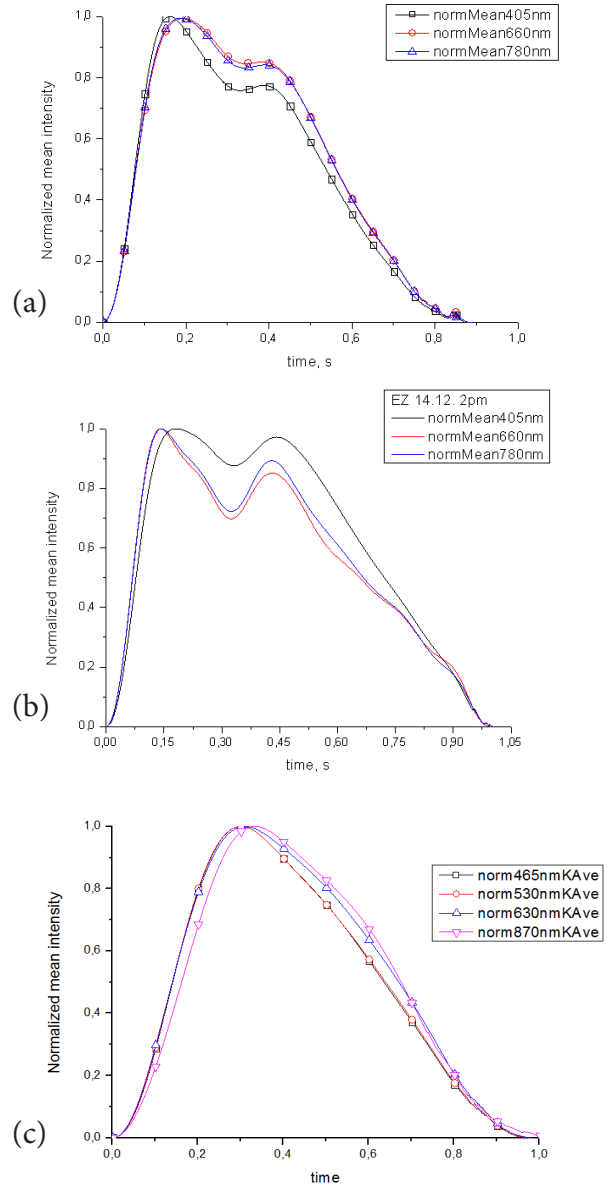

Fig. 4. (a, b) Normalised mean SPPPG signal shapes of a 3-wavelength laser diode prototype at 405, 660 and 780 nm wavelengths. (c) Normalised mean SPPPG signal shapes of a 4-wavelength LED prototype at 465, 530, 630 and 870 nm.

They proved that the device is well-suited for MS PPG measurements from the fingertip. Our next goals will be to approbate the newly developed multi-LED biosensor in clinical measurements and to better understand the differences in PPG signal shapes at different wavelengths (Fig. 4(c)) and the difference between healthy and pathological skin.

4. Conclusions

The developed laser diode biosensor prototype confirmed its ability to detect PPG signals at three laser wavelengths simultaneously and to detect temporal differences in the signal shapes at these wavelengths that correspond to different penetration depths in skin. The multi-LED biosensor prototype confirmed its ability to detect PPG signals on any place of the body at four LED wavelengths simultaneously and to detect temporal differences in the signal shapes between different wavelengths.

Analysis of MS-PPG signal shapes and baseline variations at three and four wavelengths provides information on haemo-dynamic parameters at different vascular depths and we may conclude that the developed device may be useful in dermatology for skin assessment.

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References

[1] J. Allen, Photoplethysmography and its application in clinical physiological measurement, Physiol. Meas. **28**, R1–R39 (2007).
[2] H. Ugnell and P.A. Öberg, Time variable photoplethysmographic signal: its dependence on light wavelength and sample volume, Proc. SPIE **2331**, 89–97 (1995).
[3] H.H. Asada, P. Shaltis, A. Reisner, S. Rhee, and R.C. Hutchinson, Mobile monitoring with wearable photoplethysmographic biosensors, IEEE Eng. Med. Biol. Mag. **22**, 28–40 (2003).
[4] http://www.ilo.org/safework_bookshelf/english?content&nd=857170571
[5] L. Gailite, J. Spigulis, and A. Lihachev, Multilaser photoplethysmography technique, Lasers Med. Sci. **23**, 189–193 (2008).
[6] R. Stojanovic and D. Karadaglic, A LED–LED-based photoplethysmography sensor, Physiol. Meas. **28,** N19–N27 (2007).
[7] E. Kviesis-Kipge, A new technique for optical detection of biosignals, Latv. J. Phys. Techn. Sci. (3) **46**, 64–69 (2009).
[8] L. Asare, E. Kviesis-Kipge, U. Rubins, O. Rubenis, and J. Spigulis, Multi-spectral photoplethysmography technique for parallel monitoring of pulse shapes at different tissue depths, Proc. SPIE **8087**, 80872E (2011).

ODOS MIKROAPYTAKOS ANALIZĖS DAUGIASPEKTRIS OPTOELEKTRONINIS PRIETAISAS

L. Asare, E. Kviesis-Kipge, M. Ozols, J. Spigulis, R. Erts

Latvijos universiteto Atominės fizikos ir spektroskopijos institutas, Ryga, Latvija

Santrauka

Sukurtas optinio šviesolaidžio lazerinis diodinis biojutiklis, sudarytas iš vieno daugiabangio lazerinio diodo (405, 660 ir 780 nm) ir atskiro šviesos diodo su daugiakanaliu išėjimo signalo apdorojimu ir įmontuotu Li jonų akumuliatoriumi. Sukurta speciali programinė įranga daugiaspektrės fotopletizmografijos signalams vaizdinti ir matuoti. Prietaiso prototipas išbandytas su 11 sveikų asmenų.