Multi-spectral photoplethysmography technique for parallel monitoring of pulse shapes at different tissue depths

Lasma Asare, Edgars Kviesis – Kipge, Uldis Rubenis, Oskars Rubenis, Janis Spigulis
Institute of Atomic Physics and Spectroscopy, University of Latvia, Raina Blvd. 19, Riga, LV-1586, Latvia

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 at skin surface.1 Reflection photoplethysmography detects the tissue back-scattered radiation with time resolution.2
Multi-spectral photoplethysmography (MS-PPG) biosensor is intended for analysis of peripheral blood volume pulsations at different vascular depths. The light penetration depth in skin varies depending on wavelength - for example, green light penetrates only Stratum corneum and epidermal layer (til 0.2 mm), but red and infrared radiation penetrates also in dermal layer (til 2 – 3 mm). Consequently, 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 research3 with the aim to understand more deeply pulse shape changes at different tissue depths.

METHODS
Biosensor system. Device (Figure 2.) consists of a PPG sensor, a central system control unit and a Li-ion accumulator. The signals acquired from measuring photodiode discharge time are inverse to the absorption of the light. The biosensor operates in contact reflection mode, with simultaneous sequential recording of PPG signals at each wavelength.
Protocol. Measurements were performed in a laboratory. The MS-PPG recording time was between 90 and 120 sec. The recordings were taken 5 times with pause of 2 minutes.
Subjects. The multi-spectral photoplethysmography recordings were obtained from 11 male volunteers. The volunteers were healthy men. The age of volunteers was between 22 and 40 years.
Experimental data analysis. Experimental data were analyzed with the PPG-analysis software which is a specially created for analysis (Figure 1).

EXPERIMENTAL RESULTS
To illustrate the results after analysis with both programs, Figure 3, and Figure 4, demonstrates that normalized mean PPG signal shape from all 5 measurements at wavelength 405 nm was different to signals at red and NIR wavelengths, and also systolic rising time had a shift (Figure 3.) if we compare wavelengths 405 nm, 660 nm and 780 nm.
In 70% cases we noticed systolic rising time shift of 660nm and 780nm wavelengths pulses relatively to 405nm (Figure 3a) but in 30% cases opposite effect took place (Figure 3b). This phenomenon needs further studies to be properly explained.

CONCLUSIONS
The newly developed biosensor 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 depth in skin. Our results suggest that further tests are necessary to understand the different PPG signal shape at wavelength 405 nm and the systolic rising time shift. The time interval from foot to incisura (the notch between systole and diastole) was the same independently on the PPG pulse duration. Our hypothesis about PPG signal time shifts 405nm delayed relatively to 660nm and 780nm pulses ahead is connects with hypotension or low blood pressure of the volunteers. One of the next steps will be further tests to confirm or reject this hypothesis. Analysis of the MS-PPG signal shapes and baseline variations at three wavelengths provides information on haemodynamic parameters at different vascular depths and we may conclude that newly developed method could be useful in dermatology for skin assessment, further research is needed.

ACKNOWLEDGEMENTS

REFERENCES

Image 1: PPG analysis window screenshot during processing of experimental data.

Figure 2. The prototype biosensor device.

Figure 3. Examples of PPG signal time shifts: a) 660nm and 780nm delayed relatively to 405 nm, b) 405nm delayed relatively to 660 nm and 780 nm pulses ahead.

Figure 4. Mean PPG signal shapes for each wavelength with standard deviation (SD).

Figure 5. Reflectance and absorbance spectra in the range of 400-800 nm.