# Comparison of green, blue and infrared light in wrist and forehead photoplethysmography

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**Introduction.** Photoplethysmography (*PPG*) is a non-invasive diagnostic technique for blood volume change estimation by illuminating tissue and measuring the reflected light. Traditionally, the photoplethysmography is used to measure the oxygen saturation and heart rate [1]. However, the *PPG* signals are easily contaminated by the motion artefacts, which cause distortions in the signal and corrupt measured physiological parameters [2]. There are two known sources of the motion artefacts: human tissue deformation and ambient light interference. The aim of this study is to compare three different wavelength light sources for photoplethysmography on two different measurement sites, suitable for long term monitoring.

**Modeling the PPG signal.** It is known that light of short wavelengths (blue and green) penetrates less than light of longer wavelengths (infrared) [3]. Therefore, *PPG* using shorter wavelength optical signals is less influenced by the deeper tissue movements. Fig. 1 shows the skin penetration depth of light wavelengths ranging from 400 to 1000 nm.

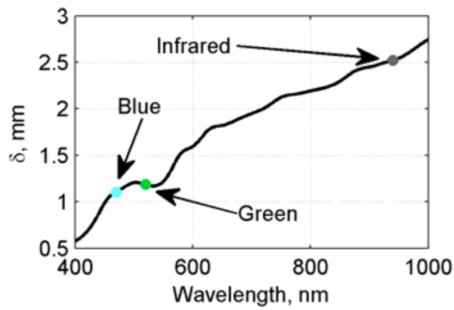


**Fig. 1.** Optical penetration depth vs. light wavelength

Calculation of the optical penetration depth has been performed including absorption and scattering coefficient values presented in [4]. Light penetration depth $\delta$ can be performed with the relation:

$$\delta = \frac{1}{\sqrt{3 \cdot \mu_a(\lambda) \cdot (\mu_a(\lambda) + \mu_s(\lambda))}}, \quad (1)$$

where $\delta$ – penetration depth, mm; $\mu_a(\lambda)$ – absorption coefficient, $cm^{-1}$; $\mu_s(\lambda)$ – scattering coefficient, $cm^{-1}$.

**Materials ant methods.** The *PPG* signals were recorded at 250 Hz sampling frequency, using Texas Instruments Inc. *PPG* acquisition evaluation kit AFE4490SPO2EVM [5] and reflectance type *PPG* sensors. Three *LED*s of the different wavelengths of light: blue (465 nm), green (520 nm) and infrared (940 nm) were used. Radiant intensities of all light sources were normalized using [6] and *LED*s' datasheets [7 - 10]. The recordings were taken at the following radiant intensities: 1.28 mW/sr, 0.82 mW/sr, 0.26 mW/sr; on two measurement sites: wrist and forehead. All recorded signals were of approximately 1 min duration. The artefacts were intentionally induced in the middle of the recordings by tapping the *PPG* sensor three times in a row. Experiments were carried out on three healthy male subjects, repeating each experiment three times.

The *PPG* signals were pre-processed with the band-pass Butterworth zero phase filter having 0.4 Hz and 7 Hz cut-off frequencies. Three criteria were chosen for the comparison of the *PPG* signals: root mean square (*RMS*) value of PPG signal before artefact, pulsating to stationary tissue component ratio (*AC/DC*) and artefact to signal ratio (*ASR*) [11], which was calculated by:

$$ASR = \frac{V_a}{V_{ppg}}, \tag{2}$$

where *ASR* – artefact to signal ratio; $V_a$ – magnitude of the *PPG* signal with artefact (during tapping the sensor); $V_{ppg}$ – average amplitude of the *PPG* signal 20 seconds before the artefact.

The *AC/DC* ratio was calculated by:

$$AC / DC = \frac{AC_{ppg}}{DC_{ppg}}, \tag{3}$$

where *AC/DC* – pulsating to stationary component ratio; $AC_{ppg}$ – magnitude of the clean *PPG* signal; $DC_{ppg}$ – the mean value of the *PPG* signal before filtering.

**Results and discussion.** Fig. 2, 3 and 4 represent the *RMS*, *ASR* and *AC/DC* ratio values of the *PPG* signals, recorded on the wrist and the forehead:

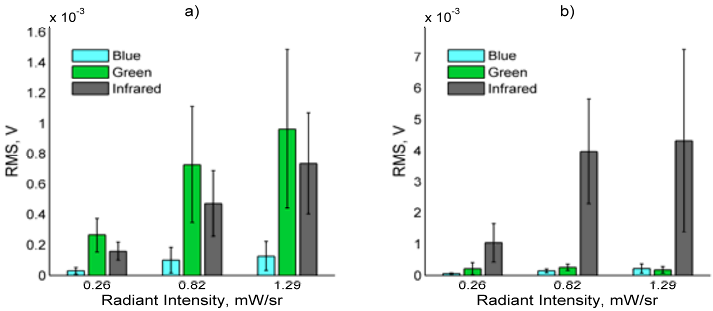


**Fig. 2** The *PPG* signal *RMS* value as the function of light intensity on: wrist (a), forehead (b)

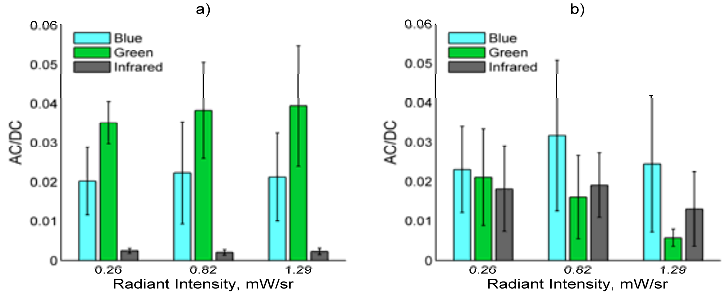


**Fig. 3.** *AC/DC* ratio as the function of light intensity on: wrist (a), forehead (b)

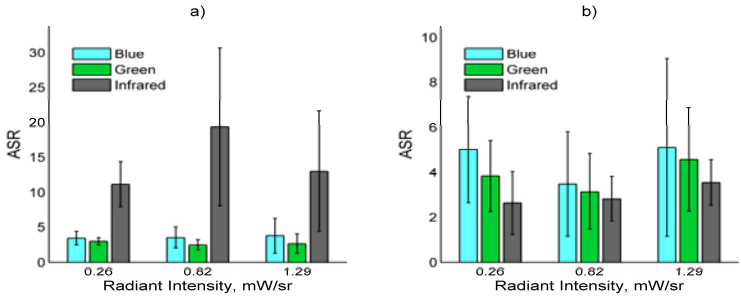


**Fig. 4.** Artefact to *PPG* signal ratio as the function of light intensity on: wrist (a), forehead (b)

The results show that the green light *PPG* has the highest *RMS* and *AC/DC* values as well as the lowest *ASR* values when using on the wrist. This suggests that the green *PPG* is more suitable for the wrist sensor application as it penetrates deep enough to sense blood pulsations and is less influenced by the *DC* component of tissues. The signals from the blue and the green light sensors are comparable in terms of *ASR* and *AC/DC* performance. Nonetheless, at the same radiant intensity, the signal from the blue light sensor is of lower amplitude thus has worse signal to noise ratio (Fig. 5). On the other hand, at equal radiant intensities, the blue light sensor consumes less power than the green light sensor. Thus the usage of blue *LED* at the radiant intensity of 1.29 mW/sr (or higher) could be taken into consideration if the low power consumption is required.

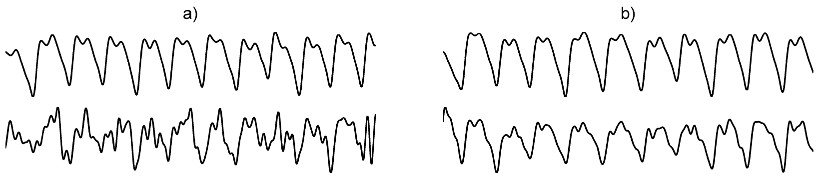


**Fig. 5** Green (top) and blue (bottom) PPG signal morphology comparison at: (a) 0.26 mW/sr and (b) 1.29 mW/sr light intensities

Because of a thin layer of the forehead tissue, all sensors performed quite well. However, the penetration of the infrared light is the highest, which makes it to reflect with more energy than both green and blue light. That is why the infrared light showed the best results in a forehead sensor – the highest *RMS* and the lowest *ASR* values at all radial intensities were obtained. However, the blue light possessed highest *AC/DC* ratio when using on the forehead, which might be related to the lower light attenuation in a non-pulsatile tissues.

**Future work.** The next goal is to expand this study by involving more subjects as well as conducting *PPG* signal quality estimations. Also, we are looking forward on investigating possible reference sources to improve motion artifact cancelation in *PPG* signals.

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## References

1. Elgendi M. On the Analysis of Fingertip Photoplethysmogram Signals. // Curr Cardiol Reviews., 2012. - P. 14-25.
2. Petterson M T, Begnoche V L, Graybeal J M. The effect of motion on pulse oximetry and its clinical significance. // Anaesthesia & Analgesia, 2007. - P. 78-84.
3. Fodor L, Ullman Y, Elman M. Aesthetic Applications of Intense Pulsed Light. // London: Springer London, 2011. P. 133.
4. Bashkatov A N, Genina E A, Kochubey V I, Tuchin V V. Optical properties of human skin, subcutaneous and mucous tissues in the wavelength range from 400 to 2000 nm. // Journal of Physics D: Applied Physics, 2005. - P. 2543-2555.
5. Texas Instruments, AFE4400 and AFE4490 // SLAU480A Development Guide, 2012. - P. 1-50.
6. DeWolf A D. Electro-optics Handbook // Burle Industries, Lancaster, PA, 1992 - P. 255.
7. Hebei I.T. (Shanghai) Co., Lt d., Blue LED PLCC2LBCT datasheet.
8. Hebei I.T. (Shanghai) Co., Lt d., Green LED PLCC2LGCT datasheet.
9. Vishay Semiconductors, Infrared LED VSML3710 datasheet, Nov. 2009.
10. Vishay Semiconductors, Ambient Light Sensor TEMD5510FX01 datasheet, Oct. 2011.
11. Maeda Y, Sekine M, Tamura T. Relationship Between Measurement Site and Motion Artifacts in Wearable Reflected Photoplethysmography // Springer Science, Business Media, 2010. - P. 969-976.

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In this study we compared *LED* light sources of three different wavelengths: blue, green and infrared for the use in wrist and forehead photoplethysmography (*PPG*). Criteria for comparison were root mean square (*RMS*), pulsating to stationary tissue component ratio (*AC/DC*) and artifact to signal ratio (*ASR*). Our study showed that the green light is the most suitable for the wrist *PPG* and an infrared light source is better for the forehead *PPG*.