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Design and development of a new non-invasive trans-reflectance photoplethysmographic probe

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Background and purpose

The technique of pulse oximetry relies on the adequate arterial pulse, which is detected as a photoplethysmographic (PPG) signal [1]. When peripheral perfusion is poor, pulse oximeter readings become unreliable or cease altogether [1]. In order to overcome some of the limitations of the commercial transmittance or reflectance pulse oximeters that appear in cases of poor PPG pulsation, a novel trans-reflectance (dual mode) finger probe that will operate simultaneously as a reflectance and transmittance PPG probe was proposed**.** Such a probe will "harvest" both the light transmitted and reflected from the vascularized tissue and could potentially enhance its performance in cases of poor peripheral perfusion.

Method

The trans-reflectance finger PPG probe was developed, which consists of two photodiodes and four LEDs (Figure 1). The geometrical placement of the optical components enables the probe to operate simultaneously in both reflectance and transmittance mode. The conventional pulse oximetry wavelength LEDs of peak emission wavelength 660 nm and 880 nm are used. These LEDs are driven asynchronously with 20 mA current.

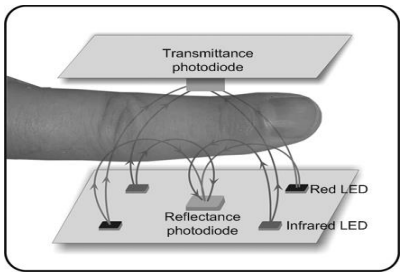

Figure 1: Trans-reflectance photoplethysmography probe.

A processing system was designed to enable simultaneous monitoring of reflectance, transmittance and trans-reflectance PPGs, allowing comparison of all three modes. The outputs from the reflectance and transmittance photodiodes were connected to two differential transimpedance amplifiers. For the trans-reflectance channel the outputs of both reflectance and transmittance transimpedance amplifiers are summed together using a summing amplifier. All three voltage outputs representing the three modes are then demultiplexed, filtered, and amplified into their respective red and infrared ac and dc PPG outputs. Low perfusion states were artificially induced by asking volunteers to place their hands in iced water.

Results

Thirteen signals were recorded, which included four PPG signals from each mode: transmittance, reflectance, and trans-reflectance acquired from the custom made trans-reflectance PPG system, and a temperature signal recorded from the thermocouple.

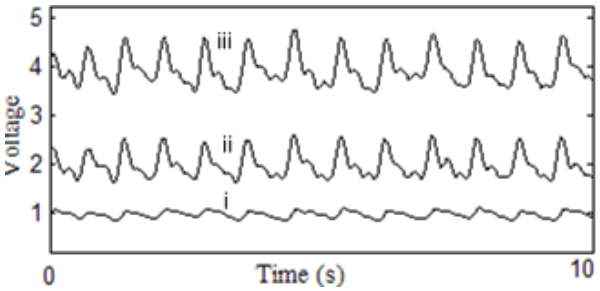

Figure 2: Data of 10-second of normalized infrared PPG signals recorded at 16 ^{0}C from the "cold" index finger.

Figure 2 shows the normalized reflectance (i), transmittance (ii), and trans-reflectance (iii) infrared ac PPG signals obtained at 16 ^{0}C from the index finger. At low temperatures, where vasoconstriction presumably occurred, a noticeable difference in the amplitude of the reflectance and transmittance PPG probe signals was observed. The infrared trans-reflectance component (iii in Figure 2), was greater in amplitude than both signals obtained from the transmittance and reflectance modes.

Conclusions

A new non-invasive trans-reflectance PPG probe was developed. The PPG probe had also the capability to operate in reflectance and transmittance mode as well. In order to compare the performance of the trans-reflectance PPG mode with the conventional modes, all three modes were run simultaneously in an artificially induced finger hypoperfusion using an ice bath. Good quality PPG signals were recorded from the newly developed tran-reflectance probe. The results show that, during hypoperfusion, the trans-reflectance mode was more sensitive to blood pulsation than the reflectance and the transmittance mode. This suggests that the trans-reflectance signals may be more suitable for estimation of oxygen saturation in cases of poor peripheral perfusion where PPG signals from the reflectance or the transmittance mode can become unreliable.

References

[1] Y. Mendelson and B. D. Ochs. Noninvasive pulse oximetry utilizing skin reflectance photoplethysmography. IEEE Trans Biomed Eng, 35(10):798–805, Oct 1988.