Evaluation of optical interference in a combined measurement system used for assessment of tissue blood flow

Zahra Abdollahi*[a], Panayiotis A. Kyriacou[a], and Justin P. Phillips[a]
[a]School of Computer Science, Mathematics and Engineering, City University London, EC1V 0HB, UK

ABSTRACT

A dual-wavelength pulse oximetry system combined with laser Doppler was developed for the assessment of perfusion. Red and infrared PPG and Doppler signals were recorded from a healthy volunteer in three studies at different measurement sites to investigate the interference between PPG and laser Doppler flowmetry (LDF). Good quality photoplethysmographic (PPG) and Doppler signals were detected simultaneously using this combined probe from the skin of the finger. The influence of the PPG light sources on LDF measurements was investigated; also the influence of the LDF light sources to the PPG measurements was studied. In the worst case, the apparent change in PPG amplitude when the LDF system was switched on was less than 8%, and the change in LDF flux amplitude when the PPG system was switched on was 14.7%.

Keywords: optical interference, photoplethysmography (PPG), laser Doppler flowmetry (LDF) and tissue blood flow

1. INTRODUCTION

Assessment of tissue perfusion can be achieved with various techniques including photoplethysmography (PPG) and laser Doppler flowmetry (LDF). In photoplethysmography, changes in transmission of light through tissue due to pulsation of small arteries can be monitored while in laser Doppler flowmetry microcirculatory blood cell velocity and flux can be studied [1]. The results presented here are part of a wider study in which a combination of LDF and PPG methods is used for assessment of perfusion in bowel tissue for patients undergoing bowel resection. Determination of bowel viability following bowel resection is essential in gastrointestinal surgery [1, 2, 3]. Monitoring blood flow in abdominal surgery especially intra and post-operatively would be a valuable tool for prevention of intestinal ischemia and necrosis, often requiring surgical re-exploration, resulting in significant postoperative morbidity and increased length of hospital stay. Although various monitoring techniques have been proposed to assess intestinal viability, none of these techniques have been proven reliable enough to replace visual observation [4]. The aim of the main study is to combine the established techniques, LDF and PPG, into one flexible probe intended for assessment of perfusion in abdominal tissue during bowel operation. Such a probe could alert the surgeon immediately of any compromise in blood flow so further investigation and if necessary, therapeutic steps can be applied immediately to prevent severe consequences. However in the present study, evaluation of optical interference between the two measurements was investigated.

1.1 Photoplethysmography (PPG)

Photoplethysmography, (PPG) a non-invasive electro-optical technique used mainly to determine and register the variation in blood volume or blood flow in the body caused by cardiovascular pulsations in the bed of tissue [5–6]. A photoplethysmographic signal is obtained by illuminating a region of tissue containing a vascular bed and acquiring either the reflected or transmitted light. Photoplethysmography (PPG) involves two basic optoelectronic components: an emitter such as a light emitting diode (LED) which illuminates the tissue and a photodiode for collecting the backscattered or transmitted. The intensity of light that reaches the photo detector can be measured which represent blood volume changes synchronous with the cardiac cycle [7].

The PPG signal consists of two components: a pulsatile (‘AC’) part, which is modulated by pulsations of (primarily) arterioles and a static (‘DC’) part which represents the light scattered from non-pulsing arterial blood, the venous and capillary blood and other static tissues. Two main PPG operational configurations include transmission and reflection

*Zahra.Abdollahi.1@city.ac.uk; phone (+44) 020 7040 3878

mode. In transmission mode operation the tissue sample (e.g. fingertip) is placed between the source and detector while in reflection mode the LED and detector are positioned adjacently [8].

1.2 Laser Doppler flowmetry (LDF)

LDF is an optical and non-invasive method for monitoring microvascular blood flow and is currently used in a variety of fields in medicine [7], assessment of burn wound depth [9], skin tumor characterization [8], amputation level determination [10,11], neurosurgery [12], and breast reconstruction [13]. It has been used also for ocular, cerebral, cutaneous, auricular, splanchnic, and renal blood flow in a wide range of laboratory animal species [14].

Laser Doppler flowmetry (LDF) and photoplethysmography (PPG) are both well-established non-invasive optical methods for measuring blood flow changes in skin [12]. As they register perfusion effects at different tissue layers, application of both these methods infers a useful overall assessment of perfusion. Laser Doppler flowmetry can investigate the more superficial blood flow [13] while PPG can assess vessel pulsation deeper in the tissue [14]. Therefore the combination of LDF and PPG techniques into a single probe for estimating the degree of perfusion at different depths simultaneously would provide a new, improved method of assessing tissue viability.

2. MATERIALS AND METHODS

2.1 Evaluation of the System

Three main parts of the measurement system were developed and used in this study. These include the probe, instrumentation and a data acquisition system. A custom-made signal processing circuit separates the photoplethysmographic signals into its AC and DC components and amplifies each component. The AC PPG and DC PPG signals together with laser Doppler signals via the analog output of a Moor Instruments VMS-LDF perfusion monitor (Moor Instruments, Axmoor, UK) are sampled using a National Instruments USB-6009 data acquisition card (National Instruments Inc., Austin, TX, USA) and saved onto a notebook computer. Software (known as a virtual instrument or 'VI') implemented in LabVIEW (National Instruments Inc., Austin, TX, USA) reads the PPG and LDF signals, displays the AC PPG waveform and records both signals in a spreadsheet file for later analysis.

2.2 Optical Probe

The reflectance probe used in this study shown in Figure 1, consist of two LEDs of two different wavelengths as light sources for PPG surrounded by one photo detector at 5 mm distance for the PPG recording. The LDF fiber tip is placed at 7 mm from the photo detector. Two wavelengths of light were used for PPG: PPGIR (λ=880 nm) and PPGR (λ=628 nm) with the same distance from light source to photo detector. The wavelength of the LDF light source was (735 nm). All these components are embedded in the board of dimensions: 2.9 cm length, 1.2 cm width and 1.8 mm thickness.

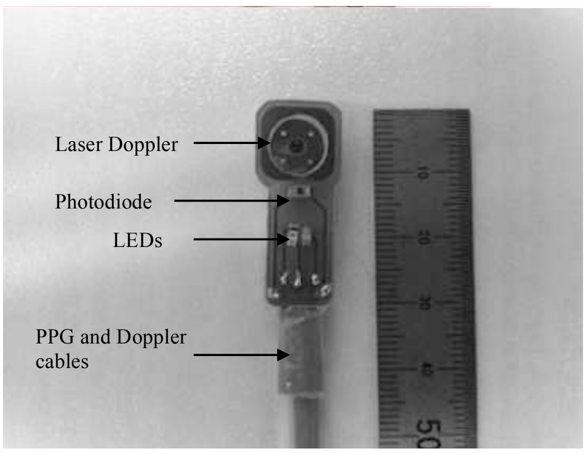

Figure 1. The combined probe with two LEDs, one photodiode and the laser Doppler probe tip of 8 mm diameter.

The laser Doppler probe used in this research is a VP8C titanium laser Doppler disc probe (Moor Instruments Ltd., UK). Figure 2 shows the block diagram of the PPG system. It consists of a timer, LED driver, photodiode detector, amplifier, demultiplexer (sample and hold); and a band pass filter circuit.

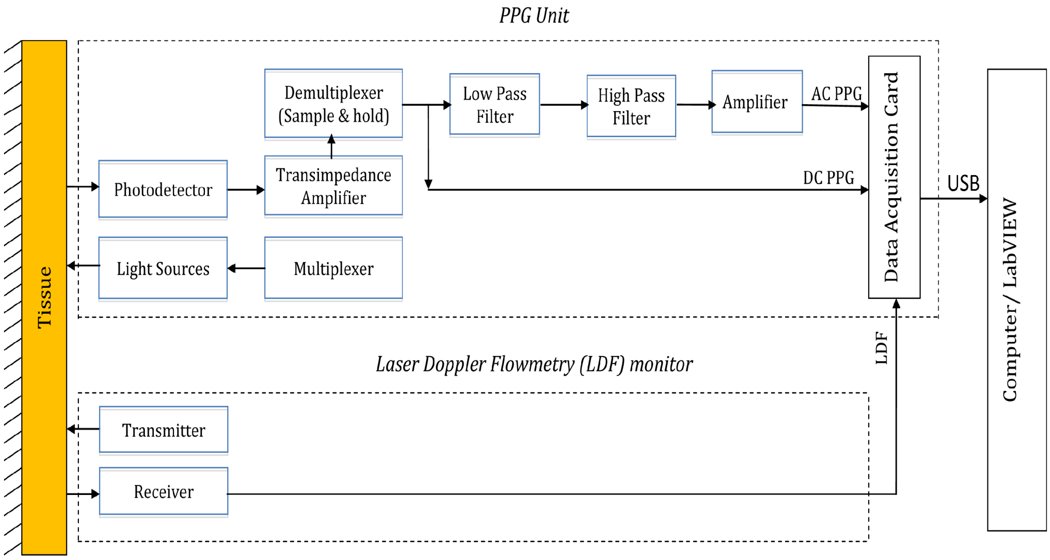

Figure 2. The block diagram of the PPG-LDF systems

2.3 Subject

For this study, one healthy subject participated. The study was approved by the City University London Senate Research Ethics committee. In vivo evaluation of the PPG and Doppler system was done on the left index finger at rest in room temperature conditions.

2.4 Experimental Method

To minimize stray light, the study was conducted in a dark room with lights off. Room temperature was 20–22˚C. In order to minimize motion induced artifacts the subjects remained silent and still during the measurement. In order to evaluate the effect of interference between PPG and LDF, three studies were evaluated in which two experiments were performed. In the first study the LDF fiber tip was placed 7 mm from the photodetector. In the second and third studies the LDF fiber was placed 20 mm and 40 mm from the photodetector respectively.

2.4.1 First study

For the first study, the LDF fiber tip was placed at 7 mm from the photo detector. The first measurement was performed to evaluate the influence from LDF on the PPG from the LDF. This measurement was first recorded for PPG with only the PPG activated for 60 seconds and then with the PPG and LDF activated for another 60 seconds. To assess the influence from PPG on the LDF, the second measurement was performed in which LDF was switched on while PPG was off for 60 seconds and then with the LDF and PPG active for another 60 seconds.

2.4.2 Second study

All measurements in the first study were repeated with different placement for the LDF probe: 20 mm from the photodiode.

2.4.3 Third study

All measurements again were repeated but this time the LDF probe was placed 40 mm from photodiode.

2.5 Data Analysis

The mean value of the LDF was calculated for each measurement. The PPG amplitude was taken as the peak-to-peak value of the AC-part of the signal. A custom made labVIEW VI was used to extract the peak-to-peak value from the acquired PPG signals. The mean PPG amplitude of each 60-second segment was then calculated.

3. RESULTS

Good quality PPG and Doppler signals were detected from the combined probe from all six experiments. The results for mean value for the measurements from first, second and third study are presented in Table 1 (a), (b) and (c) respectively.

Table 1. Mean value from measurements in the first study (a), second study (b) and in the third study (c).

Measurement		Average AC Amplitude (mV)		Mean DC (V)		Average LDF Flux (PU)
PPG	LDF	IR	R	IR	R	
ON	OFF	13.68	2.05	4.505	1.174	---
OFF	ON	---	---	---	---	38
ON	ON	14.26	2.22	4.577	1.249	43.6

(a)

Measurement		Average AC Amplitude (mV)		Mean DC (V)		Average LDF Flux (PU)
PPG	LDF	IR	R	IR	R	
ON	OFF	8.213	1.379	3.244	0.902	---
OFF	ON	---	---	---	---	51.2
ON	ON	8.396	1.407	3.659	0.991	57

(b)

Measurement		Average AC Amplitude (mV)		Mean DC (V)		Average LDF Flux (PU)
PPG	LDF	IR	R	IR	R	
ON	OFF	5.321	0.988	3.263	0.965	---
OFF	ON	---	---	---	---	38.6
ON	ON	5.333	1.002	3.38	1.01	42.4

(c)

The 60-second average IR AC in the first measurement in the first study increased slightly when the LDF was switched on. This suggests that switching on the Laser source, results in more light being detected by the PPG photodetector: an increase in amplitude of 4.07% was seen. The average for R AC with PPG on and LDF off increased by 7.66%. This shows that the R PPG is affected proportionally more by LDF than IR PPG. The average for LDF flux was seen to increase by 14.7% when the PPG light sources were turned on.

From the results of the second experiment it was found that by switching the PPG emitters on and off had less effect on the laser Doppler signal than the first experiments. The average for IR AC and R AC increased by 2.18% and 1.99% respectively when the LDF laser was switched on. Switching on the PPG light sources in the second study caused an increase of 11.3% in average laser Doppler flux.

From the results of the third experiment it was found that by switching the PPG emitters on and off this had the least effect on the LDF. The average for IR AC increased by 0.23% and 1.40% respectively. Switching on the PPG light sources in the second study caused an increase of 9.84% in the average laser Doppler flux. The IR and R DC is also affected by LDF and their amplitude reduces by switching the LDF off in all three measurements as it can be seen from the Table 1 (a), (b) and (c) but in this study the result focuses mostly on IR and R AC as well as LDF flux.

4. DISCUSSION AND CONCLUSION

This study was performed to evaluate optical interference between PPG and LDF in a combined system. This preliminary evaluation study showed that good quality PPG and LDF signals could be acquired using the new combined probe. From the all results of this experiment it was found that the PPG is not greatly affected by LDF; in the worst case the change in AC amplitude when the LDF system was switched on was less than 8%. Results from this trial study showed that by increasing the distance between the LDF and the photodiode, the effect of optical interference from LDF on both red and infrared PPG signals decreased. Also it was found that R PPG is proportionally more affected by LDF light than IR PPG. The results also show that the effect on reported LDF flux from the PPG light sources is more marked. In the worst case the change in LDF flux amplitude when the PPG system was switched on was 14.7%. Like the PPG amplitudes, it was found that increasing the distance between the LDF and the photodiode had the effect of reducing the optical interference from PPG light sources on the LDF flux values.

To ensure no significant interference occurs, the system could be equipped with optical filters (since the laser Doppler system operates at 735 nm, between the two wavelengths of the PPG system). Also the PPG-system switches between the two wavelengths, which eliminate any risk of interference between R and IR channels. Respiration artifact and other effects can be removed by addition of digital filtering.

This study was a part of a larger study, which was designed for evaluation of this new measurement system in patients undergoing bowel operation. Bowel viability assessment is essential in colorectal surgery; frequently evaluation of blood flow during and after abdominal operation can reduce the intestinal ischemia and necrosis along with an increased length of hospital stay, significant postoperative morbidity and mortality. Following to get good signals without significant interference between LDF and PPG with this combined probe, the effectiveness of this combined system was evaluated in clinical trials to assess the bowel perfusion. With this new combined sensor the presence of the blood circulation can be verified allowing early warning of any ischaemia or any other problem related to blood perfusion.

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