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Coherence Analysis of Pressure Pulse and Photoplethysmogram at Various Sites

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Abstract

Background: Health monitoring during daily life is the field with fast growing interest which leads to various biological signal measurements like photoplethysmogram (PPG) and pressure pulse (PP). PPG is a non-invasive, electro-optical method used to determine hemodynamic parameters. PPG monitoring is widely used in the healthcare as it can provide physiological information non-invasively such as oxygen saturation, heart rate, blood pressure (continuous and cuff less) and respiration rate.
Objective: Power spectral density (PSD) is a widely used feature in signal processing, as it is easily observable, measurable and varies with the frequency. This property of PSD makes it a popular feature in the medical data classification. This paper explains the design and development of prototype along with the PSD estimation and coherence analysis between the signal obtained from the prototype and a power lab based piezoelectric sensor.
Result: Study was carried out on 8 subjects (2 males & 6 females) aged between 19-41 years. It was observed that the coherence between the two fingers pulses obtained from the same senor is higher as compared to other locations.

Key words: Pressure Pulse, Photoplethysmogram, Power Spectral Density, Optical Sensor, Piezoelectric Sensor and Coherence.

Introduction

Pressure pulse and photoplethysmogram are the biological signals captured at the peripheral site. PP and PPG based estimation of blood pressure, heart rate/pulse rate and oxygen saturation is possible [15]. The work is carried out by the authors to estimate the coherence between the two bio signals. Power lab ADInstruments was used to capture the PP. Photoplethysmograph sensor was developed by the authors to capture the PPG.

a. Pressure Pulse (PP):
It is known that contact pressure of attaching sensor affects PPG amplitude. PPG amplitude is increased by pressurization until the pressure reaches transmural pressure [5].

b. Photoplethysmogram (PPG):
PPG is a low cost and simple method to access various cardiovascular parameters [14] [2]. PPG probe can be of two types; Reflectance Type and Transmittance type [18]. In the reflectance type probe source and detector are placed on the same side of the measurement site. While in the transmittance type probe, source and detector are placed on the opposite side of the measurement site. Figure 1 shows the two modes of PPG, transmissive and reflective.

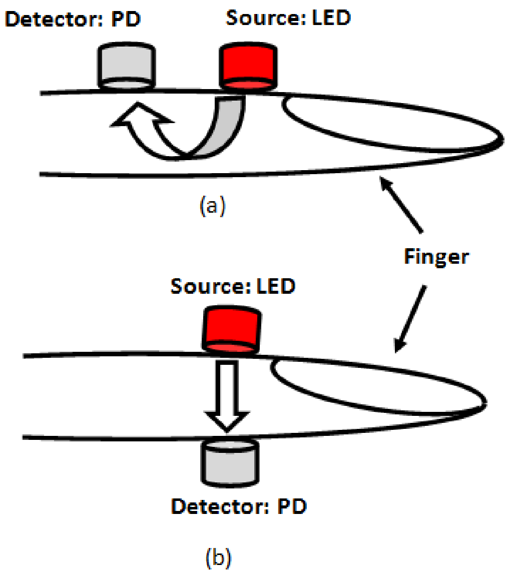


Figure 1: Modes of PPG Probe: (a) Reflective Mode & (b) Transmissive Mode

Photoplethysmogams are widely used for oxygen estimation (SpO_2) in the blood (Pulse Oximetry). SpO_2 measurement requires compound PPG sensor with two source wavelengths (Red-660nm and Infrared-940nm). SpO_2 is empirically related to the ratio of transmitted/reflected infrared and red light intensity [3]. Authors have used single wavelength reflectance type PPG sensor with a source wavelength of 860 nm and OPT 101- Silicon Burr Brown diode as a detector. Visible light source e.g. red LED can also be used as a source, but the penetration of visible light source into the body is lesser as compared to the penetration of Infra Red (IR) light source. OPT 101 can be used as a detector for visible as well as IR light source. Figure 2 shows the standard PP and PPG obtained from subject.

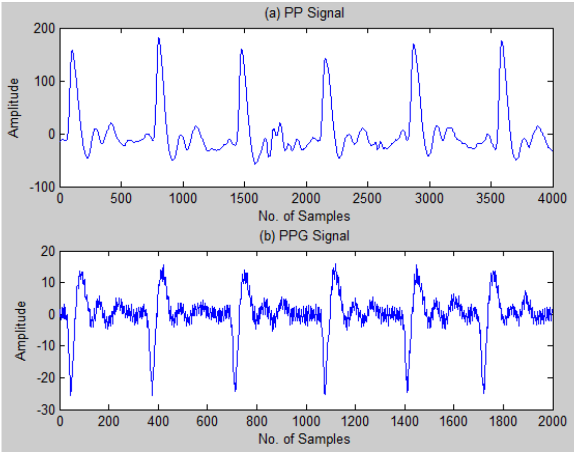


Figure 2: Pressure Pulse & Photoplethysmogram

Materials and Methods

This section covers the system block diagram, short introduction to Power Lab and the sensors used during the study, signal conditioning diagram for the PPG sensor.

a. System Block Diagram:

Figure 3 shows the system block diagram. PP is captured using a power lab sensor attached through a ADIntruments signal conditioning box attached to windows PC. While PPG is captured using designed prototype and was observed on DSO.

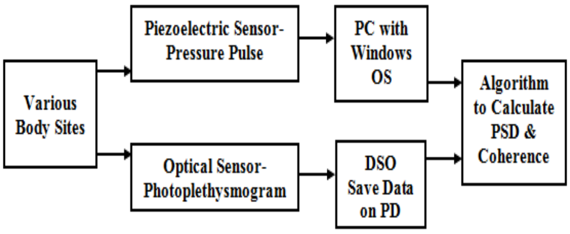


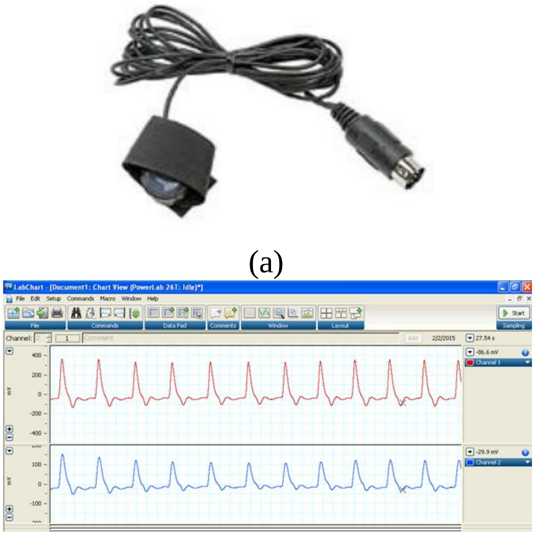
Figure 3: System Block Diagram

b. Power Lab:

ADInstruments had developed Power Lab hardware and when it is combined with ADInstruments software a multichannel real time acquisition with variable sampling rate and analysis of various bio signals can be carried out.

c. Piezoelectric Sensor:

MLE1010 is the Piezo electric pulse transducer used to record the changes in the peripheral pressure pulse by converting from the finger BP into an electrical signal like voltage. Figure 4 shows the piezoelectric sensor and the pressure pulse captured by using Power Lab.



(a)

(b)

Figure 4: (a) Pressure Pulse sensor & (b) PP acquired using Power Lab

d. Beer-Lambert's Law:

Optical PPG acquisition based on Beer-Lambert's law of spectroscopy [6] [7]. It states that the light travelling through a uniform medium with absorptive substance is reduces exponentially with the optical path length through the medium and absorptive coefficient [1] [16]. During the acquisition of PPG light travels through various mediums such as; skin, bone, tissue, skin pigmentation, venous blood and arterial blood. [17]

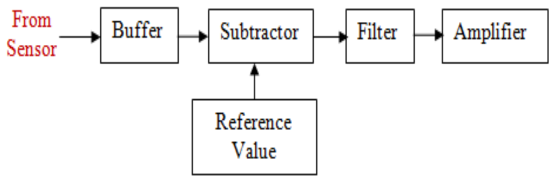
$$I(z) = I0 \exp(-\mu a z)$$

Where $I(z)$ is the attenuated intensity as a function of the distance z in the tissue, $I0$ is the incident intensity and μa is the optical absorption coefficient at the wavelength of interest [4]. The penetration depth of light is dependent on its wavelength and infrared light reaches deeper tissues than visible light [5]. So infrared light source of wavelength 860 nm is used by the authors to capture PPG from various body sites.

e. Photoplethysmogram Sensor:

Figure 5 shows the PPD sensor developed by the authors and the block diagram of signal condition circuit used.

(a)



(b)

Figure 5: (a) Photoplethysmography Sensor (b) Analog Signal Conditioning Circuit Schematic

Signal conditioning unit consists of buffer, subtractor, filter and amplifier stage. Subtractor stage is used to separate the AC and DC components of the PPG waveform. AC part is because of pulsatile arterial blood (PPG wave), while DC component is variable value which depends on thickness of tissue and the skin colour of a subject. Unwanted DC signal is removed with the help of subtractor circuit. Artifacts and noise removal is carried out by using the filter stage. Arterial pulse has very low amplitude do amplifier stage is added to the circuit.

f. Sensor Specifications:
Table 1 shows the various specifications of the prototype developed by the authors.

Table 1: Design specifications of PPG Sensor

Category	Requirements
Sensor	Reflectance Type
Source	860 nm (5 mm LED)
Detector	OPT 101
Sensor Casing	Black Polyurethane
Optode Distance	1.5 mm
Supply	10V DC-Signal Conditioning Circuit 5V, 2 KHz AC to source
Application	
Measurement Site	Anywhere on the human body from head to toe.

g. Power Spectral Density:
Power spectral density (PSD) shows the strength of the variations (energy) as a function of frequency. That means it shows strong and weak variations with respect to the frequencies [9]. The unit of PSD is energy per frequency (width) is the unit of power spectral density. So estimation of PSD at the specific frequency range yields better results. PSD computation is carried out by the fast fourier transform (FFT) or autocorrelation function. Fourier transform (FT) of a signal do not exists if non-zero average power is not square integrable. The Wiener-Khinchin theorem provides a easy alternative in such a case. The PSD is the FT of the autocorrelation function $R(\tau)$, of the signal assuming the signal in a wide-sense stationary random process. The power

of the signal in specific frequency band can be calculated by integrating over negative and positive frequencies. Hence the power spectral density generalizes to finite time-series x n with $1 \leq n \leq N$,such as a signal sampled at discrete times x n = x(nΔt) for a measurement period T = N Δt. [8]

$$Sxx(w) = \frac{(\Delta t)^2}{T} \left| \sum_{n=1}^{N} Xn\ e^{-iwn} \right|^2$$

h. Coherence Analysis:

Coherence is a measure of the amount of phase stability between two different time series. Coherence combines something analogous to the Pearson product-moment correlation to the phase angles between two signals. For the constant phase difference between two signals coherence is equal to one and for the random phase difference between signals coherence is zero. It is possible for there to be a constant phase angle difference at two different frequencies. [1] In the later case the terminology is cross frequency coherence or bi-spectral coherence or n: m phase synchrony. If the measures are within the same frequency band then it is known as coherence and it assumes auto-frequency coherence. Coherence is mathematically analogous to a Pearson product-moment correlation and therefore is amplitude normalized, however coherence is a statistic of phase differences and yields a much finer measure of shared energy between mixtures of periodic signals than can be achieved using the Pearson product moment correlation coefficient of amplitudes. Coherence estimation is important because the degree of relationship/coupling between any two living systems can be fully understood with knowledge of its frequency structure over a relative long period of time. Another advantage of coherence estimation is its dependence on the consistency of the average phase difference between two time series. [8] [9] The Pearson product-moment correlation coefficient is independent of phase differences. The fine details of the temporal relationship between coupled systems are immediately and sensitively revealed by coherence.[12] [13]

$$Cxy = \frac{|Gxy|^2}{Gxx * Gyy}$$

Where,
Gxy: is a cross-spectral density between x and y,
Gxx: is a auto spectral density of x,
Gyy: is a auto spectral density of y, and
Cxy: is a coherence between x and y.

Data Acquisition & Collection Procedure

PPG and pulse-transducer data was simultaneously recorded for one minute from Cummins College of Engineering for women for ten healthy volunteer subjects (2 males and 8 females, aged from 19 to 41 years). All subjects were in the seated position, their index fingers lying comfortably on the table. Pressure pulse data acquisition was carried-out with a Power Lab by using MLE 1010 probe (ADInstruments, Inc.).[11]

Results

The system was tested for the real signals. Pressure Pulse and Photoplethysmogram signal from various body sites were captured for eight subjects (two males and 6 females) aged between 19 to 41 years. Figure 6 (a) shows the PPG signal captured at finger, (b) power spectral density of a PPG signal and (c) is the coherence between the PP and PPG signal captured from peripheral site.

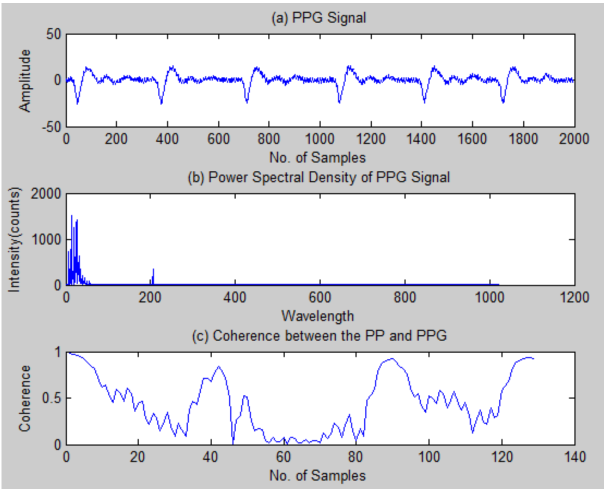


Figure 6: (a) PPG (Optical Sensor) of Left finger (b) PSD of a PPG Signal & (c) Coherence between PP and PPG

Table 2 shows the mean value of PSD of a PP signal captured by using piezoelectric sensor and PPG signal by using optical sensor. Table 3 shows the mean value of coherence estimation between the two signals.

Table 2: Mean Power Spectral Density

Two Sensors at Various Sites	Mean PSD
Optical Sensor at Fore Head	0.6848
Optical Sensor at Left Finger	10.3680
Optical Sensor at Right Finger	12.6635
Piezoelectric Sensor at Right Finger	68.4570
Piezoelectric Sensor at Left Finger	710.2814
Piezoelectric Sensor at Neck	1063

Table 3: Mean value of Coherence between the sites

Two Sensors at Various Sites	Mean Coherence
P (Left Finger) and O (Right Finger)	0.4422
P (Neck) and O (Right Finger)	0.2063
O (Fore Head) and O (Right Finger)	0.1875
O (Left Finger) and O (Right Finger)	0.8891
P (Left Finger) and P (Right Finger)	1.0000

PSD values for the optical signal were low as compared to the piezoelectric sensor. It was seen that when both signals captured by either optical sensor or piezoelectric sensor, then coherence obtained between the two signals was higher.

Conclusion

PPG signal varies in amplitude, shape and upstroke time with respect to the measurement site. The origin of the pulse-transducer signal is purely mechanical (changes in finger diameter *z* in) but the PPG originates from optical properties changes in the banana-shaped tissue path [10] between the source of light and the photo detector (μa in). It was observed that the estimated PSD for the optical signal is low as compared to the mechanical signal. Simultaneous combinational PPG and PP based data is recorded from the various body sites. Finally, the coherence estimation through both optical and mechanical methods is compared. The strong morphological similarity between the two signals was seen at the finger site with low DC component. Whereas in large arteries blood density changes exist and affect the PPG, such changes do not occur in the fingertip and consequently the AC part of the PPG at this location is only due to pulsations in the small arteries [4].

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