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Statistical Analysis of Pulse Acquired from various Body sites using Piezoelectric and Optical Transducer

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Abstract: 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 monitoring is widely used in the healthcare because of its invasiveness, reliability and ability to predict the cardiovascular parameters indirectly. PPG is captured by using optical transducer and PP is captured by using piezoelectric transducer. The pressure pulse is a purely mechanical signal where as the PPG signal is based on optical properties. This paper explains the statistical analysis of the signal obtained from the optical transducer (developed prototype) and a power lab based piezoelectric transducer. The study was carried out on real subjects; 2 males & 4 females aged between 18- 65 years with mean age of 37 years. Statistics is important in the field of engineering and data collection, as it provides the various means to analyze the physical or non-physical collected data. It was observed that the p-value of the finger PPG and PP is almost same. This shows high level of similarity between the two signals.

Keywords*:* Pressure Pulse, Photoplethysmogram, Optical Sensor, Pressure Sensor, Statistical Parameters.

1. INTRODUCTION

With every heart beat, variation in the blood volume or blood flow occurs at any given site. These variations can be captured in the form of pulse. When such a variation is captured by using photoelectric plethysmograph then it is known as photoplethysmogram or PPG. Such variations can also be captured by mechanical means by using piezoelectric transducer and then the captured pulse is known as pressure pulse or PP [3].

1.1 Pressure Pulse (PP)

Pressure pulse is the difference between the systolic (SBP) and diastolic pressure (DBP) reading. Being a mechanical transducer the contact pressure of attaching sensor affects amplitude of pressure pulse. PP amplitude is increased by pressurization until the pressure reaches transmural pressure. It is one of the very important mortality predictor [4].

1.2 OPTICAL PULSE (PHOTOPLETHYSMOGRAM-PPG)

Various cardiovascular parameters can be accessed from simple, low cost, optical signal known as PPG. Photoplethysmogams are widely used for in the blood oxygen estimation (SpO_2); technique is widely known as Pulse Oximetry. Compound PPG sensor with two source wavelengths (Red-660nm and Infrared-

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940nm) are used for blood oxygen estimation. SpO_2 is empirically related to the ratio of transmitted/ reflected infrared and red light intensity. Single source wavelength of 860 nm is used by the authors in the developed prototype. Working of the PPG probe is based on the Beer Lambert's Law [5].

1.3 BEER-LAMBERT'S LAW

Optical PPG acquisition based on Beer-Lambert's law of spectroscopy. 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 [8]. During the acquisition of PPG light travels through various mediums such as; skin, bone, tissue, skin pigmentation, venous blood and arterial blood.

$$I(z) = I0 \exp(-\mu\alpha z) \quad (1)$$

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 [2]. The penetration depth of light is dependent on its wavelength and infrared light reaches deeper tissues than visible light. So infrared light source of wavelength 860 nm is used by the authors to capture PPG from various body sites [6,7]. Figure 1 shows the plot of absorption of light with respect to its wavelength.

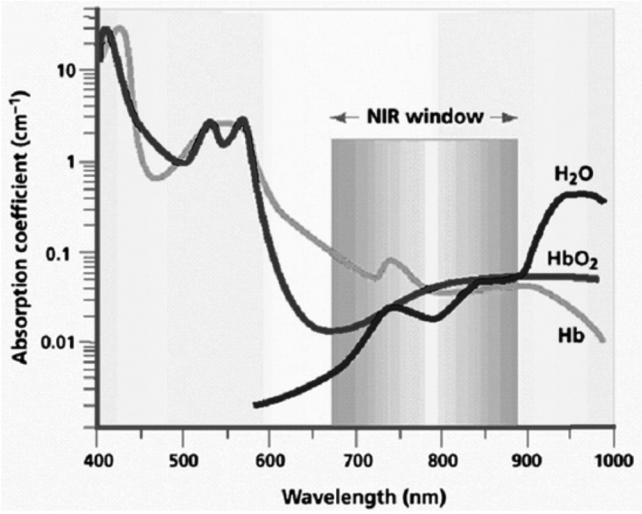


Figure 1: Wavelength Vs Penetration Plot (Rui Wang et al, 2014)

1.4 TYPES OF PPG PROBES

PPG can be acquired by using two types of probes; Reflectance Type Probe or Transmittance Type Probe. Source and detector are place on the same side of the measurement site in the reflectance type of probe. Such a type of probe can be used to acquire PPG from any measurement site. Thickness of the tissue, skin and bone do not matter in this case of probe. Figure 2 shows the reflectance and transmittance type of PPG probe. Source and detector are placed on the opposite side of the measurement site in the transmittance type of probe. Such a probe can be used to acquire PPG from a measurement site having lesser tissue and bone thickness, such as finger or toe. This is the biggest limitation of such a probe. Simultaneous PP and PPG data is recorded from the various body sites. Finally, the very commonly used statistical values for optical method and mechanical method are compared.

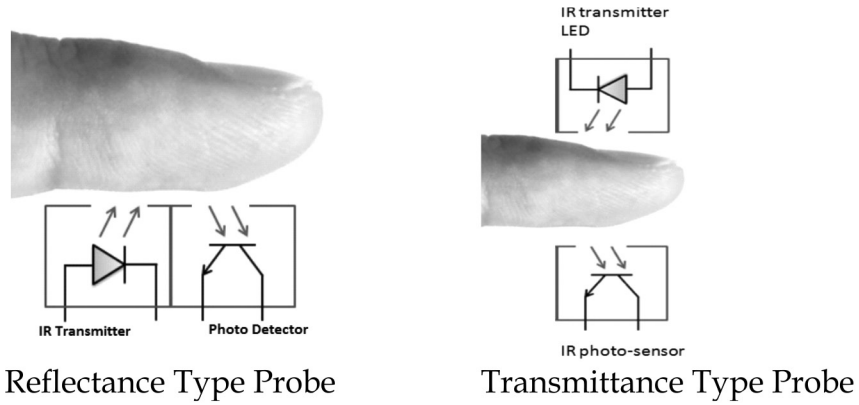


Figure 2: Types of PPG Probes (Embedded Lab, 2009)

2. MATERIALS AND METHODS

The block diagram of the system is explained in this section along with ADInstruments based PowerLab related details and optical sensor and mechanical sensor (Pressure) used to capture the pulse from various sites. Various statistical parameters used to analyze the captured data are also discussed in this section.

2.1 System Block Diagram

Figure 3 shows the system block diagram.

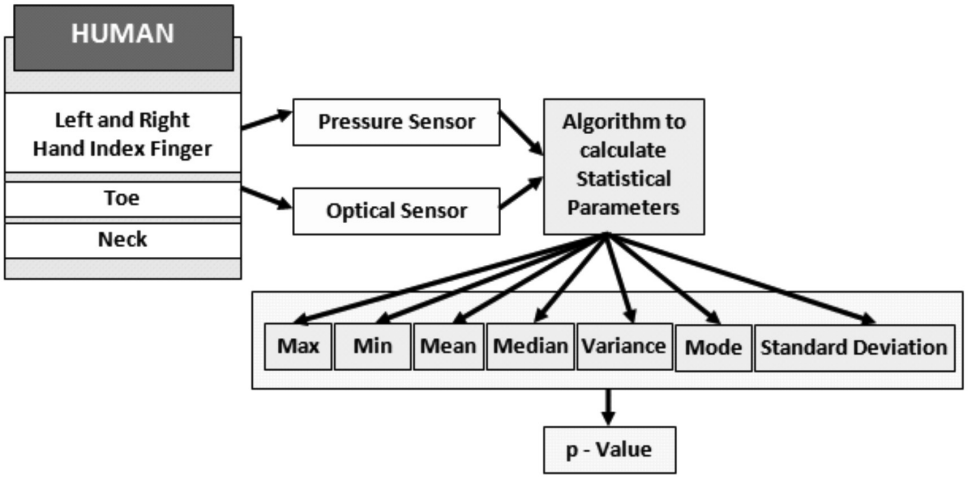
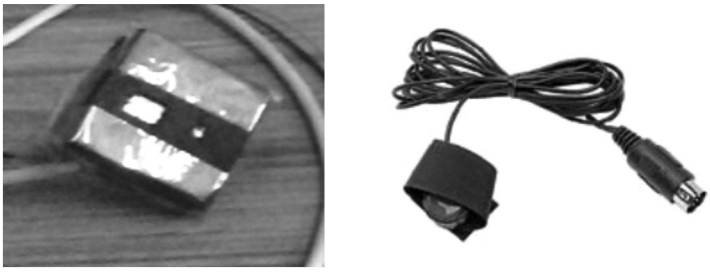


Figure 3: System Block Diagram

Power Lab: It is a high performance USB based DAQ with reliable performance and flexible connectivity. Power Lab 26T (LTS) with Lab Chart, Lab Tutor, dual Bio amplifier and 4 analog inputs is used to capture the pressure pulse. Pulse transducer use a piezoelectric sensing element, it converts the applied force into an electrical signal. With every heart beat blood volume at the peripheral site changes; this change in the blood volume is recorded as a pressure pulse by using PowerLab based TN1012/ST pulse transducer [1].

Optical pulse recorded from peripheral site is also known as photoplethysmogram (PPG). For PPG acquisition optical sensor is developed by the authors. It uses a LED with wavelength of 860 nm as a source

and OPT 101 as a detector. Figure 4 shows the optical sensor developed by the authors and the pressure sensor by ADInstruments.



Optical Sensor Pressure Sensor [2]

Figure 4: Optical Sensor and Pressure Sensor

2.2 COMPARISON OF SENSOR SPECIFICATIONS

Table 1 shows the specification details of pressure sensor and optical sensor.

Table 1

Specifications of two Sensors

Pressure Sensor	*Optical Sensor*
Piezoelectric Crystal	Source: 860 nm (5 mm LED) & Detector: OPT 101 (Silicon photodiode)
Casing: Rubber	Casing: Black Polyurethane
Excitation: 230 V AC to Signal Conditioning Box.	Excitation: 12V DC-Signal Conditioning Circuit and 10V, 2 MHz AC to source
Manufacturer: Power Lab	Manufacturer: Designed by the authors
Weight: ~ 20 gm	Weight: ~20 gm
Size: 1 cm diameter	Size: 2x2.5 cm (size can be further reduced by keeping inner PCB smaller)
Shape: Circular	Shape: Rectangular
Cable: Non shielded	Cable: Shielded – 4 core
Measurement Site: Finger, Toe and Neck only.	Measurement Site: Anywhere on the human body from head to toe.

Statistical Parameters

Various statistical features studied in this paper are:

- Mean: It is the average value of the data set. Addition of all the data points divided by the total no. of data points gives the mean value. It is also known as average value of the data.
- Min and Max: In statistics, min max is also called smallest and largest observation respectively.
- Mode: It is the value that appears most frequently in the given data set. Actually the mean, mode and median are the three kinds of averages.
- Standard Deviation: It measures the amount of variation/dispersion from the average. Low standard deviation indicates that the data points are very close to the mean value and higher standard deviation shows that the data points are spread out.

- Variance: It is defined as a measure of dispersion of set of data points around the mean value. In statistics and probability theory, variance measures how far the set of numbers is spread out. Zero value of variance indicates that all the data points are identical. Variance is always a non-negative value. Lower value of variance indicates that the data is very close to the mean and higher value indicates that the data is spread out around the mean and each other.
- P-value: It is probability under the assumption and generally used for null hypothesis testing. It helps to determine the significance of the results. Smaller p-value (<0.05) indicates the rejection of null hypothesis, while larger p-value indicates the acceptance of null hypothesis. In this paper authors have calculated the p-value for pressure pulse and optical pulse based on its previously mentioned various statistical measures.

3. SUBJECTS AND DATA ACQUISITION PROCEDURE

Photoplethysmogram (PPG) and Pressure Pulse (PP) data was simultaneously recorded for 60 seconds from six healthy volunteer subjects of Cummins College of Engineering for women. Out of six subjects, 2 were males and 4 were females, aged between 18 to 65 years with mean age of 37 years. While recording the data, all subjects were in the seated position, their index fingers lying comfortably on the table and foot resting on the ground through sandals. Data acquisition was carried-out with a PowerLab and associated probes [1].

4. RESULTS

MATLAB based PPG data filtering is carried out before the further processing. Following figure shows the filtered PPG signal captured from left finger, right finger, neck and toe.

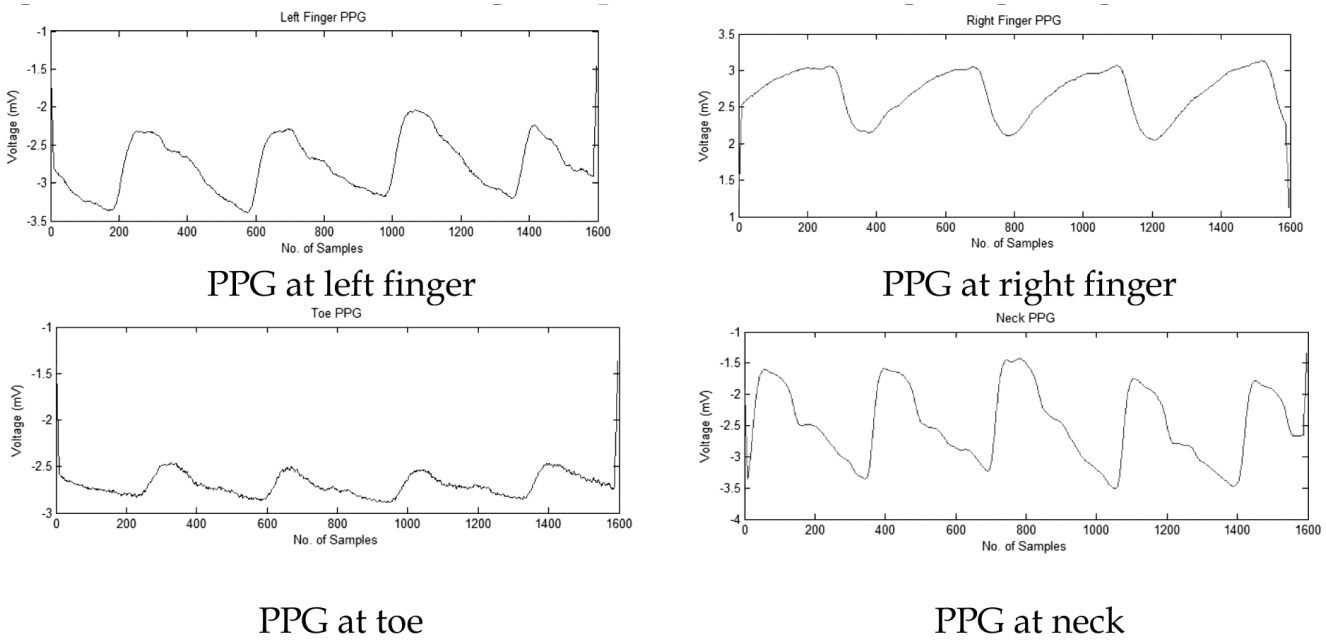


Figure 5: PPG captured from various body sites

Figure 6 shows the PP captured by using PowerLab based piezoelectric transducer at left finger, right finger, toe and neck. Further data filtering is not required for this pulse, as software based filtering is already done in the PowerLab.

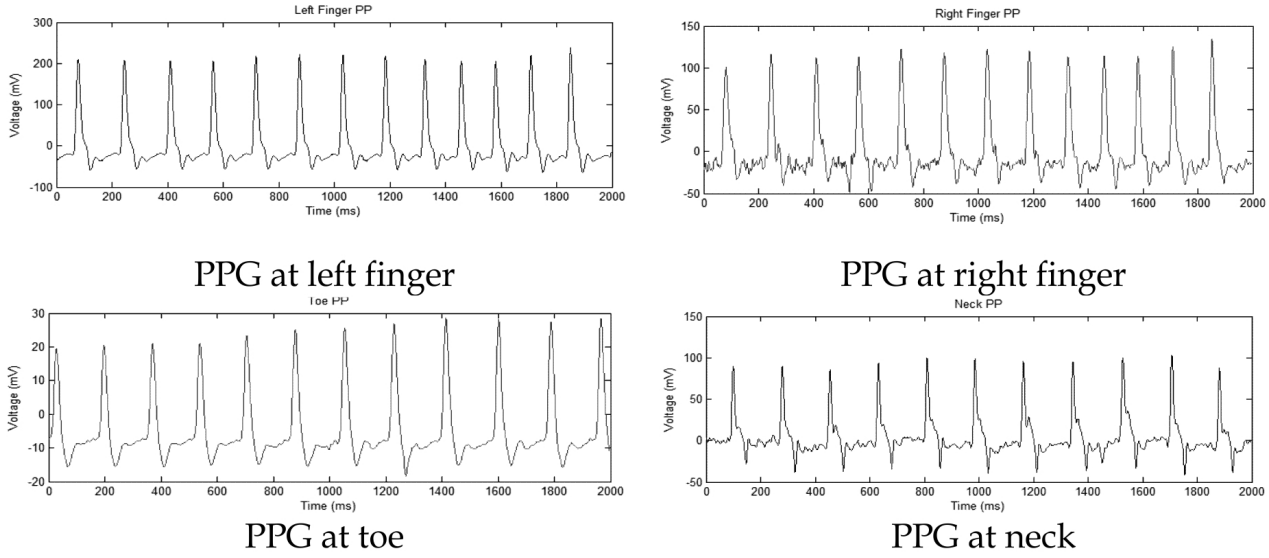


Figure 6: PP captured from various body sites

Various statistical parameters such as min, max, mean (average), mode, standard deviation and variance is calculated for each signal captured by using piezoelectric transducer and optical transducer. Table 2 shows the statistical parameters of pressure pulse (captured by using piezoelectric transducer) captured from left-right finger, toe and neck.

Table 2

Statistical Parameters of Pressure Pulse

Site	*Subject*	*Mean*	*Min*	*Max*	*Mode*	*Std Dev*	*Variance*
Left Finger	1	0.39	-57.15	181.40	-14.34	47.27	2.2e+003
	2	0.20	-86.09	212.32	-5.67	57.83	3.3e+003
	3	-11.79	-144.07	378.39	-44.71	107.41	1.15e+004
	4	0.10	-65.14	237.64	-31.14	63.99	4.09e+003
	5	-0.62	-53.81	246.71	-23.98	61.95	3.83e+003
	6	2.20	-42.03	197.17	-20.20	52.20	2.72e+003
Right Finger	1	0.41	-12.06	37.43	-7.27	14.67	215.21
	2	-0.58	-48.54	133.79	-17.62	37.14	1.37e+003
	3	0.79	-11.90	72.03	-8.37	18.54	344.02
	4	1.28	-21.65	90.86	-10.55	26.55	705.03
	5	2.55	-51.37	293.42	-24.81	63.66	4.05e+003
	6	0.36	-19.53	76.75	-9.39	20.48	419.50
Toe	1	-5.31	-18.33	28.48	-9.16	9.86	97.32
	2	-2.80	-13.11	36.30	-6.25	10.29	106.04
	3	-0.93	-5.08	13.11	-2.24	3.16	10.00
	4	-1.08	-10.89	41.84	-4.98	10.66	113.66
	5	-1.26	-46.16	121.25	-13.20	34.02	1.15e+003
	6	-3.15	-16.03	10.72	-4.77	4.04	16.37

Neck	1	0.20	-86.09	212.32	-5.67	57.83	3.34e+003
	2	3.45	-41.18	103	-5.65	23.12	534.97
	3	3.88	-98.23	190.85	-13	45.19	2.04e+003
	4	1.78	-15.77	21.95	-5.09	6.68	44.69
	5	2.54	-36.62	110.07	-7.60	20.33	413.65
	6	-0.43	-84.03	149.94	-31.99	40.35	1.62e+003

Table 3 shows the statistical parameters of photoplethysmogram i.e. optical pulse (captured by using optical transducer) captured from left-right finger, toe and neck.

Table 3

Statistical Parameters of Optical Pulse

Site	*Subject*	*Mean*	*Min*	*Max*	*Mode*	*Std Dev*	*Variance*
Left Finger	1	0.2246	-26.8800	12.8800	0.5600	5.7070	32.5697
	2	0.0260	-1.3280	0.7000	0.0640	0.3765	0.1417
	3	0.0267	-0.5120	0.3520	0.0340	0.1686	0.0284
	4	0.0360	-0.3180	0.2860	0.0640	0.1188	0.0141
	5	0.0324	-1.2400	0.8440	0.0780	0.3718	0.1382
	6	0.0392	-0.7600	0.5000	0.0080	0.2556	0.0653
Right Finger	1	0.2639	-25.5600	15.8400	0.7200	6.3066	39.7727
	2	0.0054	-27.7200	18.7200	-0.3600	6.2971	39.6530
	3	0.4344	-3.2000	2.6000	1	1.1617	1.3497
	4	0.2986	-3.8000	1.8000	1.4000	1.4876	2.2130
	5	0.0134	-1.6800	1.4560	0.0960	0.5880	0.3457
	6	0.0362	-2.1560	2.0640	0.1360	0.8427	0.7102
Toe	1	0.0220	-0.3360	0.2940	0.0240	0.1264	0.0160
	2	0.0263	-0.3180	0.2360	0.0320	0.1160	0.0134
	3	0.0268	-0.2220	0.1540	0.0360	0.0772	0.0060
	4	0.0284	-0.4200	0.5680	-0.0640	0.1913	0.0366
	5	0.0329	-0.2140	0.1940	0.0340	0.0818	0.0067
	6	0.0345	-0.2220	0.2140	0.0120	0.0849	0.0072
Neck	1	0.0592	-2.3720	1.1200	0.1640	0.6391	0.4084
	2	0.0275	-0.2400	0.3280	0.0160	0.0949	0.0090
	3	0.0361	-0.3040	0.2400	0.0320	0.0866	0.0075
	4	0.0461	-1.1960	0.6720	0.0640	0.3429	0.1176
	5	0.0349	-0.6100	0.2840	0.0820	0.1588	0.0252
	6	0.0403	-1.5380	0.9760	0.1700	0.3571	0.1275

Table 4 shows the p-value for various measurement sites using pressure pulse and optical pulse with alpha equal to 0.05. Microsoft Excel software was used to carry out the ANOVA (single sided) on the data.

Table 4

p-value for the Pressure Pulse and Optical Pulse with alpha=0.05

For Pressure Pulse	
Measurement Site	*p-value*
Left Finger	0.253863
Right Finger	0.008578
Toe	0.129916
Neck	0.000255
For Optical Pulse	
Measurement site	*p-value*
Left Finger	0.254031
Right Finger	0.007705
Toe	5.83E-12
Neck	1.4E-06

5. CONCLUSION

With respect to the measurement site changes in the PPG signal were observed in amplitude, shape and upstroke time. The pressure pulse signal is purely mechanical (changes in finger/toe 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). The work was carried out on 6 healthy volunteers (2 males and 4 females) aged between 18 – 65 years. It was observed that, as age increase the shape of the pressure pulse and optical pulse changes. Amplitude of the PP and PPG is generally higher for the male volunteers as compared to the female volunteers of the same age. Statistical analysis was applied to a captured PP and PPG data to analyze and interpreted results in the form of variation in the data. It was observed that the p-value of the PP and PPG for the left and right finger is approximately same. Therefore, the strong morphological similarity between the two signals was observed.

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