Determination of Heart Rate and Arterial Stiffness using LabVIEW and MatLab

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Abstract: The use of optical techniques is becoming increasingly widespread in biomedical monitoring and analysis because of its non-invasive nature. Physiological parameters are usually determined by characterization of temporal and spectral properties of the interaction between light and anatomy. Photoplethysmography is an optical technique which reflects the changes in blood volume and can be used for diagnosis of various disorders related to blood flow as well as monitoring the human pulse wave.

Keywords: Photoplethysmography, Augmentation Index, Stiffness Index, Non-invasive.

1.Introduction

Photoplethysmography is one of the most popular methods for measuring the changes in blood volume. It is based on optical absorption of arterial blood and is widely used in current clinical practice [1], [2]. This paper describes a blood flow monitoring system for early diagnosis of various diseases related to blood flow. The analysis of pulse signal or photoplethysmogram (PPG) signal helps us to understand arterial pathologies, which is a major contributor to cardiovascular diseases. Arterial stiffness occurs due to biological aging and arteriosclerosis. The increasing stiffness of the arterial wall leads to an increased risk of cardiovascular events such as myocardial infarction and stroke, the two common causes of death in the modern society [3]. Hence to prevent premature death, it is important to determine the cardiac risk of a patient beforehand.

The purpose of the study is to develop a non-invasive technique for monitoring the changes in blood flow for diagnosis of various diseases due to any blood flow disorders. The human pulse signal or PPG signal can be extracted using optical means. An LED-photodetector set up is used to measure the changes in blood flow which is acquired by using NI USB 6009 Data Acquisition (DAQ) card. The DAQ card is interfaced with the PC with LabVIEW. The acquired data is processed in LabVIEW and the PPG signal is extracted. Further the morphology of the PPG waveform is analysed in MatLab and various parameters like systolic peak, diastolic peak, pulse interval and delay time are estimated. The heart rate (HR) and stiffness index (SI) are calculated for obtaining the degree of arterial stiffness.

2.Overview of PPG Signal

Photopletyhysmogaphy is mainly used to determine as well as register the changes in blood volume or blood flow in the body which occurs with each heartbeat. It is an optical measurement technique which is used to determine the blood volume changes in the micro vascular bed of tissue. This technique is employed non-invasively and it requires only a few optoelectronic components: a light source and a photodetector [4]. Light source used today is typically a red or infrared LED, the sensor is typically a phototransistor used along with filters to pass light of relevant wavelengths. The light is allowed to pass through a translucent site with good blood flow. Typical measuring sites are fingertip, earlobe or toe. There are two modes of sending light through the measuring site: transmission and reflectance. In the transmission mode, the light source and the detector are placed opposite to each other with the measuring site in between. In the reflectance mode, the light source and the detector are placed next to each other on top of the measuring site. The phototransistor perceives the non-absorbed light from the LED which is a reflection of the human pulse signal.

3.Analysis of PPG Signal

The appearance of the human pulse signal or PPG signal is divided into two phases: the anacrotic phase and the catacrotic phase.

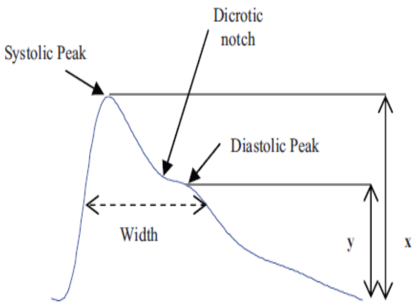


Figure 1: A typical PPG waveform

The anacrotic phase is the rising edge of the pulse which is primarily concerned with the systole. The catacrotic phase is the falling edge of the pulse which is concerned with diastole and wave reflections from the periphery. A dicrotic notch is usually seen in the catacrotic phase of subjects with healthy compliant arteries [5].

Some of the parameters that can be determined by analyzing the morphology of the PPG signal are as follows:

a) *Systolic Peak:* Pulsatile changes in blood volume.
b) *Delay Time (ΔT):* Time between systolic peak and diastolic peak.
c) *Pulse interval:* Time between beginning and end of the PPG waveform.

d) *Heart Rate (HR):* Heart rate is calculated as follows:

$$HR = 60/\text{pulse interval}$$

e) *Stiffness Index:* The stiffness index can be determined by using the following formula [6]:

$$SI = h/\Delta T,$$

Where h is the height of the subject.

4.Methodology

The block diagram of the proposed system is shown in figure 2. For extracting the signal a fingertip PPG sensor is designed. The fingertip PPG sensor consists of a red LED and a phototransistor. The LED emits light to the tissue and a small amount of emitted photons is detected by the phototransistor. The signal from the phototransistor is passed through a high pass active filter which attenuates the frequency below 1.4 Hz. The output is then interfaced to the PC with LabVIEW using NI USB DAQ 6009 card. After extracting the signals in LabVIEW, a database of different subjects is created which is finally exported to Matlab for further processing.

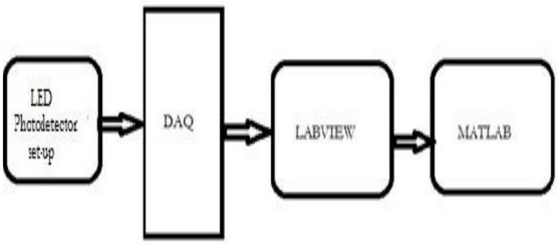


Figure 2: Block Diagram of the Proposed System

In LabVIEW, a block diagram window and a front panel window appears. In the block diagram window the programming code is prepared and in the front panel window the result is displayed. The LabVIEW block diagram is shown in figure 3. The acquired signal is passed through a pair of filters. In the first filter block a low pass filter with cut off frequency of 30 Hz is used to remove the noise present in the acquired PPG signal or pulse signal. In the second filter block a smoothing filter is used to smooth the signal. The collector block is used to collect 1000 samples of the signal and finally the desired filtered signal is displayed in the front panel as shown in figure 4.

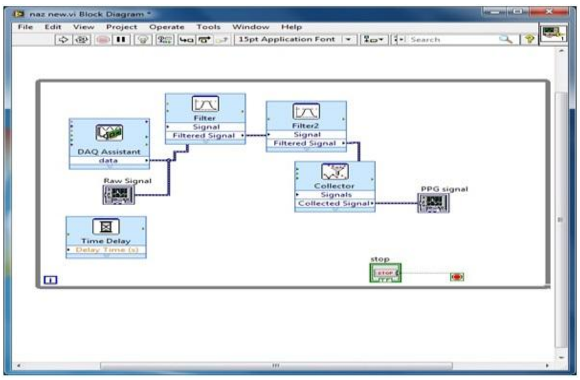


Figure 3: LabVIEW Block Diagram

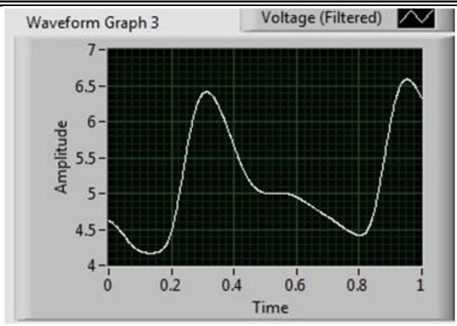
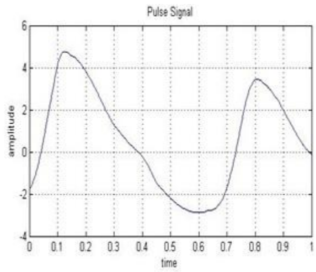


Figure 4: Front Panel

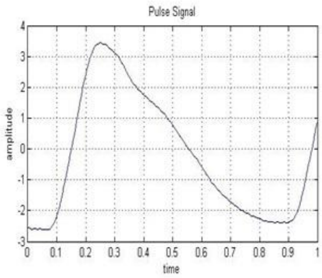
5.Results

After extracting the signal in LabVIEW, a database of 9 subjects comprising 5 male and 4 female subjects is created. The PPG waveforms of 9 subjects along with the calculated parameters are as follows:



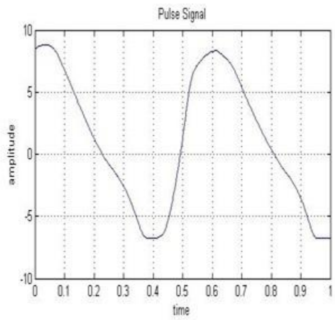
Height	1.76
Systolic Peak (Volts)	4.8
Diastolic Peak (Volts)	-0.9
Augmentation Index (AI)	0.18
Delay Time (sec)	0.27
Stiffness index (SI) (m/s)	6.51
Pulse Interval (sec)	0.75
Heart Rate (bpm)	80

Subject 1: Male, Age: 20 yrs



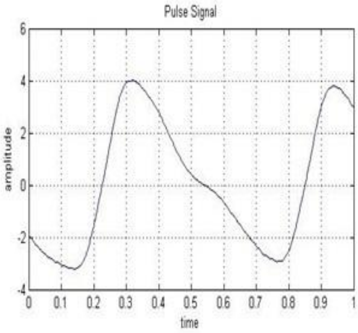
Height (m)	1.73
Systolic Peak (Volts)	3.4
Diastolic Peak (Volts)	1.1
Augmentation Index (AI)	0.32
Delay Time (sec)	0.23
Stiffness index (SI) (m/s)	7.52
Pulse Interval (sec)	0.80
Heart Rate (bpm)	75

Subject 2: Male, Age: 24



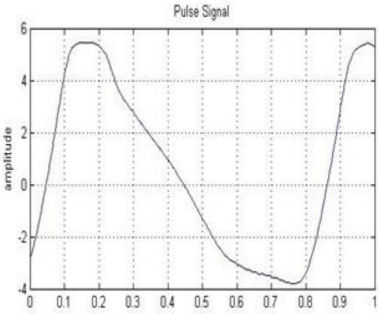
Height (m)	1.52
Systolic Peak (Volts)	8.5
Diastolic Peak (Volts)	-2.5
Augmentation Index (AI)	0.29
Delay Time(sec)	0.22
Stiffness index (SI) (m/s)	6.90
Pulse Interval (sec)	0.70
Heart Rate (bpm)	85

Subject 3: Male, Age: 28



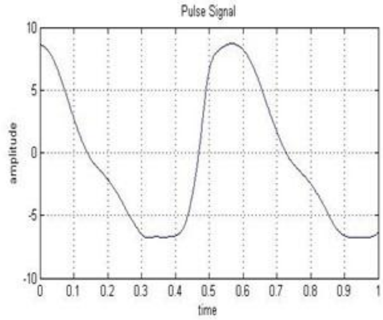
Height (m)	1.67
Systolic Peak (Volts)	4
Diastolic Peak (Volts)	-0.72
Augmentation Index (AI)	0.18
Delay Time (sec)	0.21
Stiffness index (SI) (m/s)	7.95
Pulse Interval (sec)	0.65
Heart Rate (bpm)	92

Subject 4: Male, Age: 30



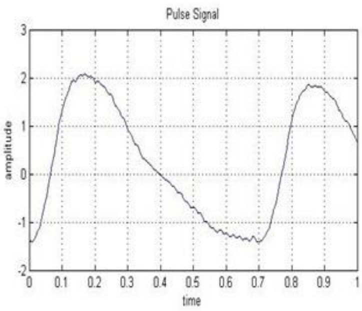
Height (m)	1.76
Systolic Peak (Volts)	5.5
Diastolic Peak (Volts)	2
Augmentation Index (AI)	0.36
Delay Time (sec)	0.18
Stiffness index (SI) (m/s)	9.78
Pulse Interval (sec)	0.80
Heart Rate (bpm)	75

Subject 5: Male, Age: 45



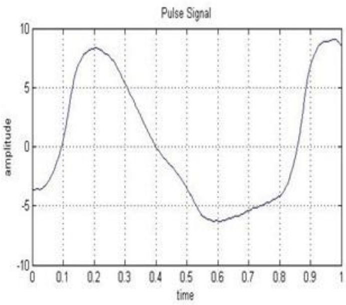
Height (m)	1.67
Systolic Peak (Volts)	9
Diastolic Peak (Volts)	-2.1
Augmentation Index (AI)	0.23
Delay Time (sec)	0.25
Stiffness index (SI) (m/s)	6.68
Pulse Interval (sec)	0.62
Heart Rate (bpm)	96

Subject 6: Female, Age: 20



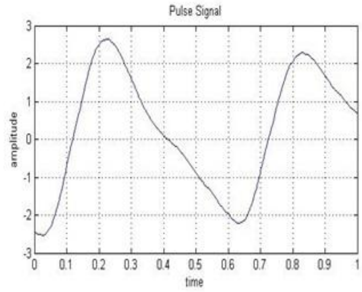
Height (m)	1.70
Systolic Peak (Volts)	2.1
Diastolic Peak (Volts)	-0.9
Augmentation Index (AI)	0.42
Delay Time (sec)	0.24
Stiffness index (SI) (m/s)	7.08
Pulse Interval (sec)	0.68
Heart Rate (bpm)	88

Subject 7: Female, Age: 26



Height (m)	1.64
Systolic Peak (Volts)	8.8
Diastolic Peak (Volts)	-3
Augmentation Index (AI)	0.34
Delay Time (sec)	0.22
Stiffness index (SI) (m/s)	7.45
Pulse Interval (sec)	0.75
Heart Rate (bpm)	80

Subject 8: Female, Age: 28



Height	1.70
Systolic Peak (Volts)	2.7
Diastolic Peak (Volts)	-0.5
Augmentation Index (AI)	0.18
Delay Time (sec)	0.19
Stiffness index (SI) (m/s)	8.94
Pulse Interval (sec)	0.69
Heart Rate (bpm)	86

Subject 9: Female, Age: 30

6. Discussion

The heart rate of all the 9 subjects (5 male/ 4 female) is summarized in Table I.

Table I: Heart Rate

Subjects	Age (yrs)	Heart Rate (bpm)	Theoretical Comment	Clinical Aspects
Subject 1	20 M	80	Normal	Normal
Subject 2	24 M	75	Normal	Normal
Subject 3	28 M	85	Normal	Normal
Subject 4	**30 M**	**92**	**Normal**	**Tachycardia**
Subject 5	45 M	75	Normal	Normal
Subject 6	**20 F**	**96**	**Normal**	**Tachycardia**
Subject 7	26 F	88	Normal	Normal
Subject 8	28 F	80	Normal	Normal
Subject 9	30 F	86	Normal	Normal

The range of normal resting heart is 60-100 bpm theoretically. If the heart rate is below 60 bpm, it is termed as bradycardia. If the heart rate is above 100 bpm, it is termed as tachycardia. Clinically, if the heart rate is above 90, it is considered as tachycardia and that subject may require special attention. The heart rate above 90 may be a sign of hyperthyroidism or anaemia. Here subject 4 and subject 6 are found to be tachycardiac.

The stiffness index of all the 9 subjects (5 male/ 4 female) is summarized in Table II.

Table II: Stiffness Index

Subjects	Age (yrs)	Stiffness Index (m/s)
Subject 1	20 M	6.51
Subject 2	24 M	7.52
Subject 3	28 M	6.90
Subject 4	30 M	7.95
Subject 5	45 M	9.78
Subject 6	20 F	6.68
Subject 7	26 F	7.08
Subject 8	28 F	7.45
Subject 9	30 F	8.94

The normal range for stiffness index is $5m/s \leq SI < 15m/s$. Out of all the subjects, the arterial stiffness index of subject 5 is the highest. Higher arterial stiffness index means the arteries are getting hardened. Arterial stiffness slowly increases with increment of age in healthy subjects [7]. However, in diabetic subjects, it increases rapidly. In our result we have found that subject 5, who is diabetic, has higher stiffness index value. So, after few years subject 5 may exceed the normal range for stiffness index. Hence, subject 5 requires special attention.

7. Conclusion

A non-invasive technique of measuring the heart rate and arterial stiffness which is an important marker for determining atherosclerosis and predicting the risk of cardiovascular disease has been presented in this paper. The advantage of non-invasive method is that they reduce pain. Hardware and algorithm advances in the field of bio-photonics are beginning to broaden its use outside the traditional operating room and critical care areas. Further investigations can be carried out to observe the changes in the parameters of subjects with known peripheral arterial disease.

Acknowledgement
We would like to thank all the other faculty members, teaching and non-teaching staff at Dept. of ECE, ADBU for all their help and support which motivated us to propose the work in a proper manner.

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