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Detection and Evaluation of Vascular Wall Elasticity using Photoplethysmography Signals in Sinus Rhythm Subjects

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Abstract

Objectives: This study analyzes the dilation and constriction (elastic) properties of blood vessels using a non invasive Photoplethysmography method. The dilation and constriction of blood vessel changes as a function of aging which can be analyzed using the shape of Phototplethsymogram. **Methods:** A preliminary test is conducted in twenty sinus rhythm subjects in the range between 20 to 73 years. **Findings:** The parameters like peak ratio, time ratios, valley to peak ratio, stiffness index and augmentation index are the indices to determine the dilation and constriction properties of the blood vessels. **Applications/Improvements:** The above parameters are evaluated with the help of appropriate hardware and software. Neural networks is trained using these parameters to classify the level of elasticity, using which the abnormalities such as Atherosclerosis, aortic stenosis, aortic regurgitation can be diagnosed.

Keywords: Atherosclerosis, Dicrotic Notch, Peak Ratio, Photoplethysmography, Sinus Rhythm

1. Introduction

Vascular elasticity is the physical property of a blood vessel that returns to its original shape after dilation which is caused by blood volume increase. The vascular elasticity changes as a function of aging and can be analyzed using the peripheral pulse waveform shape.

The transmission of pulse wave depends upon the elasticity of blood vessels when the walls of the arteries are more distensible the pressure rise is less and so the transmission of pulse is less. When the arterial wall losses its elastic properties and becomes rigid as in old age the pressure rise is more and transmission of pulse is more[1,2]. The blood enters to the arteries and causes the walls of the arteries to stretch which in turns makes the pressure to increase about 120 mmHg. At systole condition when the left ventricle stops ejecting the blood and when the aortic valve closes, the pressure in the arteries is maintained high during the diastolic condition. The Dicrotic notch of the peripheral pulse is shown in Figure 1 occurs due to aortic valve closure.

The peripheral pulse wave is recorded by the Photoplethysmograph. The PPG in general determines the properties of the vascularity during the cardiac cycle. The vascularity changes are observed during aging and disease conditions[3-5].

In the younger subjects, the pulse signals exhibits a rise and a notch on the slope, whereas in the older subjects, the peripheral pulse signals denotes more gradual rise, fall and no pronounced dicrotic notch is observed. The parameters of interest in the Photoplethysmogram are the ratios of P2/P, V/P1, t2/t1[6]. (Refer Figure 3).

It is reported[7] that there is a considerable change is in the stiffness index characterizes the stiffness in arteries

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and there is also a relationship between the age and k value which is a function of systolic, diastolic and mean blood pressure. As age progress the k value starts increasing, which indirectly represents the stiffness of arteries. Huifeng Yang et al.[8] reported that the amplitude of 0.9 Hz component of pulse waveform and the age are related.

It is well known that the classification by neural networks depends on the number of parameters used in training. So we have extracted another parameter namely Augmentation Index[9] which is taken as the ratio of voltage difference between diastolic peak and systolic peak and the systolic peak. Making use of the parameters declared above, classification can be performed to determine various the levels of elasticity according to the age groups as good, average and poor. These levels can be used for diagnosing the arteriosclerosis which is abnormal condition of cholesterol deposition[10,11].

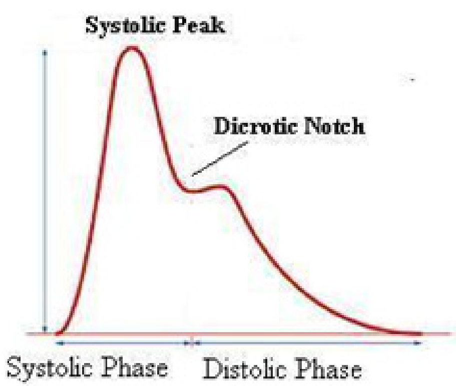

Figure 1. Diagrammatic representation of peripheral pulse wave.

2. Methodology

The methodology used to acquire and analyze the relevant parameters is explained in the following sections.

2.1 Measurement System

The block diagram of the PPG recording system used in this study is shown in Figure 2. The reflection type PPG method is used to record the pulse signals from the limbs of the subjects. The light emitting diode at 640nm is used as a source and a LDR is used as the detector. The hardware was implemented using precision instrumentation amplifier in a common mode configuration. The bandwidth of the PPG amplifier is 0.5 to 5 Hz and the amplifier is designed to eliminate high frequency noise[12]. Cathode Ray Oscilloscope (CRO) SW340 is used to display the waveform and the captured signals are transmitted from the CRO to the PC using the RS232 interface. All the measurements were done manually and all the statistical results were plotted using the Win STAT in Excel.

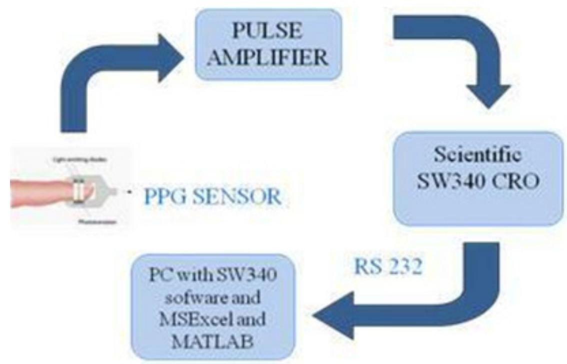

Figure 2. Block diagram of the proposed system.

2.2 Pulse Measurement

PPG signal measurements were obtained from 17 healthy subjects in sinus rhythm (12 male, 5 female). All the sinus rhythm subjects were divided into different age groups, 20-30 years and 30-40 years, 40-50 and 50-73. All the subjects were informed about the test and they were medically examined to exclude from any cardiovascular diseases. Non hypertensives subjects were excluded from this study. The subject's systolic, diastolic and mean blood pressures were measured using the patient monitoring system for further analysis. A finger sensor developed for this measurement purpose is attached to the forefinger of the right hand of each subject. The entire PPG recordings were done for 60 seconds for the further analysis.

2.3 Analysis

The waveforms were analyzed offline using scientific sw340 software. A sample of one cycle and parameters measured is shown in Figure 3. P1 represents amplitude of systolic peak from the base. P2 represents the amplitude of the diastolic peak from the base. V represents the amplitude of Dicrotic notch from the base.T1 represents the time period of one cycle. T2 represents the time difference between systolic peak and Valley. Δt represents the time difference between systolic and diastolic Peak. Δv represents voltage difference between systolic and diastolic peak[7].

The Software reads the waveform from the CRO and display the waveform in the screen of the computer. The values P1, P2, V, T1, T2, Δt, Δv are measured using SW340 software and the ratios P2/P1, V/P1, T2/T1 [3], SI [4], AI [6] is calculated. The blood pressure measured from the patient monitoring system is monitored which is used the measure the value of K. All the calculated values are used to plot the graph. KNN (k Nearest Neighborhood algorithm) is used to cluster the data into three classes of level of elasticity namely good, average and low.

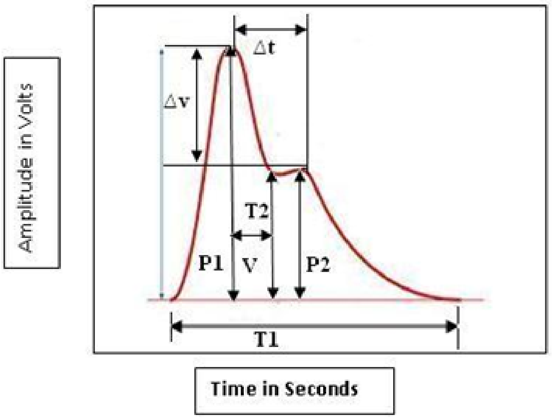

Figure 3. Diagrammatic representation of PPG signal.

3. Results

A Photoplethysmographic signal is recorded from the 17 subjects of different age group from the designed hardware. The PPG signal recorded from 26 year old male and the 73 year old male is shown in the Figures 4 and 5 respectively. Age of the subject determines the peripheral pulse to a great extent. The pulse changes as the age differs which can be visually observed

waveform analysis results.

The recorded signals are used to measure the parameters mentioned in the Figure 3. The ratios P2/P1, V/P1, T2/T1, SI, AI is calculated. All the ratios are calculated for all the 17 subjects. The scatter plot of each ratio was plotted against age. The plots of all ratios are shown in the Figure 6. For each graph linear trend line is also drawn. Figure 6(a) shows the age dependence of the ratio between P2/P1. The figure depicts that the ratio P2/P1 increases with age. Figure 6(b) shows the age dependence of the ratio between T2/T1 and the ratio decreases with age. The remaining parameters valley to systolic peak ratio (V/P1), Valley to diastolic peak ratio (V/P2), Augmentation Index, stiffness, ratio, are also increases with age as shown in Figure 6c, 6d, 6e and 6f respectively.

KNN algorithm is used to classify the level of elasticity. 8 subjects from the age group from 20 to 30 years is used and 5 subjects from 30 to 50 is used 4 subjects from 50 to 70 is used to classify to 3 different classes namely good average and poor respectively.

The mean value from each group is calculated. Each input from all the three classes were used to test by measuring the Euclidean distance from the mean of each group. The minimum distance from the mean of each class is used to classify the three level of elasticity. Out of these 17 subjects, 13 subjects are classified correctly into three different groups and 4 subjects are classified wrongly.

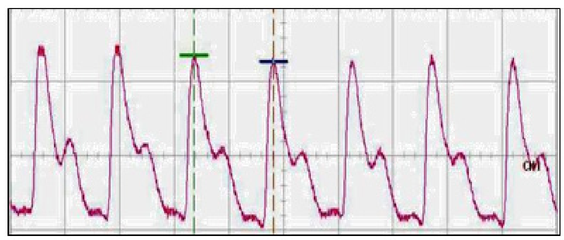

Figure 4. PPG signal recorded for a 26 year old healthy male subject.

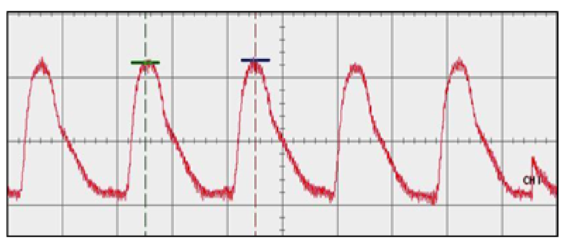

Figure 5. PPG signal recorded for a 73 year old healthy male subject.

4. Discussions

The elasticity of blood vessels can be indicated by the above mentioned parameters. There are more features to indicate the elasticity as a function of aging defined as methodological aspects[13]. KNN are used to classify the level of elasticity as good average and poor. KNN classified 13 subjects correctly and 4 subjects wrongly and this can be improved by extracting more features from PPG and

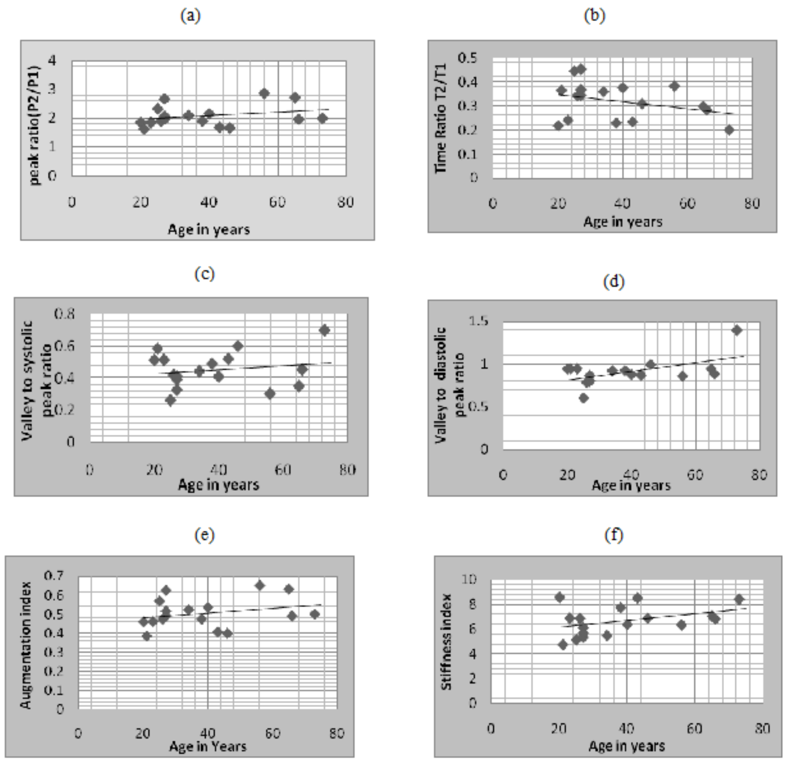

Figure 6. **(a)** (P2/P1) peak ratio, **(b)** (T2/T1) time ratio, **(c)** Valley to systolic peak ratio, **(d)** Valley to diastolic peak ratio, **(e)** Augmentation Index, **(f)** Stiffness Index.

the level of classification can be done by neural networks which will classify more accurately compared to KNN. It is possible to find the abnormalities arteriosclerosis by measuring the elasticity.

5. Conclusion

Early detection of arteriosclerosis is possible by applying this neural network based technique. There are some other abnormal condition such as aortic stenosis, Aortic regurgitation where shape of the pulse is changed. These can also be diagnosed by measuring the above parameters and neural networks can be used for the automatic classification of diseases. In future work it is decided to extract more features from PPG and to use back propagation network for better classification purpose.

6. Acknowledgements

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