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An Optoelectronic Sensor Configuration for the Determination of Age Related Indices Using Blood Volume Pulse

[1,2]Jayasree V. K, [1,3]Shaija P. J, [1]Manu P. John, [1]P. Radhakrishnan
[1]International School of Photonics
Cochin University of Science & Technology, Kochi-22, Kerala, India
[2] College of Engineering, Adoor, Kerala, India
[3] Model Engineering College, Thrikkakara, Kochi-24, Kerala, India
Tel.: +91 4842575848, fax: +91 4842576714
E-mail: jayasreevk@gmail.com, http://www.photonics.cusat.edu

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Abstract: The aim of this work is to study noninvasively the systolic and diastolic characteristics of the resting peripheral volume pulse using a normalized mean pulse as a function of age using an indigenously developed hardware setup. Evaluation of the minimum rise time (MRT), Stiffness index (S.I) and the ratio between the pulse height at the dicrotic notch of the blood volume pulse (P_0) and the systolic peak (P_1) demonstrated strong correlations with age. The younger age group had lower MRT, S.I, and P_0/P_1 values when compared to the older group. This study establishes the usefulness of the blood volume pulse contour analysis in determining the changes in the elastic properties of the vascular system with age. *Copyright © 2008 IFSA.*

Keywords: Blood volume pulse, photoplethysmograph, dicrotic notch, stiffness index, minimum rise time.

1. Introduction

Photoplethysmography (PPG) provides an estimation of cutaneous blood flow by measuring the dynamic attenuation of infrared light by the blood volume present in tissue. The contour of the pulsatile component of the PPG signal has been found to include content descriptive of vascular health [1]. PPG pulse signals can be easily obtained from the tissue pads of the ears, fingers and toes where there is a high degree of superficial vasculature [2]. An influence of vascular aging on the contour of the peripheral volume pulse in the upper limb is well recognized [3]. Large artery stiffness can be assessed from the peripheral blood volume pulse (BVP) which in turn can be obtained using PPG [1-3].

The contour of the BVP is determined mainly by the characteristics of the systemic circulation, including pressure wave reflection and Pulse Wave Velocity (PWV) of pressure waves in the aorta and large arteries [4]. This paper reports the usefulness of the analysis of the blood volume pulse contour following the derivation of the mean pulse function. Several previously reported works on contour analysis [2-4] were evaluated using the hardware setup developed in our laboratory to investigate their overall concurrence, specifically with regard to the effects of aging. In the present study we have examined the timing and amplitudes of discrete components of the BVP to formulate certain indices of the contour of the BVP which are expected to be related to age. Normalization and signal processing of the acquired data were also examined so as to arrive at an almost error free measurement of the age related indices. Since it is outside the scope of this paper to compare all of the approaches mentioned in literature with regard to pulse wave analysis, we have chosen the three parameters minimum rise time (MRT), stiffness index (S.I) and the ratio between the pulse height at the dicrotic notch of the blood volume pulse (P_0) and the systolic peak (P_1) as representative means of characterizing the pulse wave. It may be noted that each considers shape changes during a different portion of the BVP. The computations for determining each parameter demands careful consideration of issues like sampling rate, filter implementation, normalization & maintenance of signal integrity.

2. Materials and Methods

2.1. Measurement System

A schematic of the recording system used is shown in Fig. 1. The PPG signals were recorded in the reflection mode with a self designed probe and measurement setup [5]. Fig. 2 shows the layout of our hardware setup. The source used was a light emitting diode transmitting IR light at 940 nm and a photodiode was used as the detector. The hardware was implemented using FET input and ultralow offset operational amplifiers. The bandwidth of the PPG amplifier was 0.5 to 8 Hz, so as to eliminate low frequency baseline fluctuations as well as the high frequency noise. All the signals were recorded using a Tektronix (TDS5104 B) digital phosphor oscilloscope and the sampling rate used was 500 Hz. All processing and post-processing were done using MATLAB and Origin software.

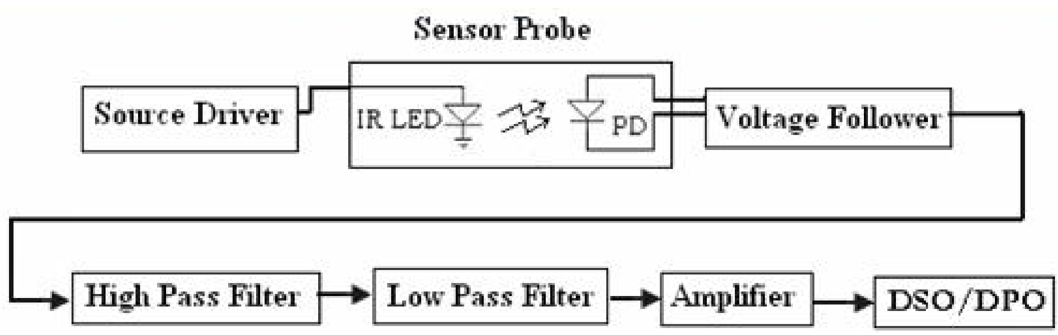

Fig. 1. Schematic diagram of the experimental setup.

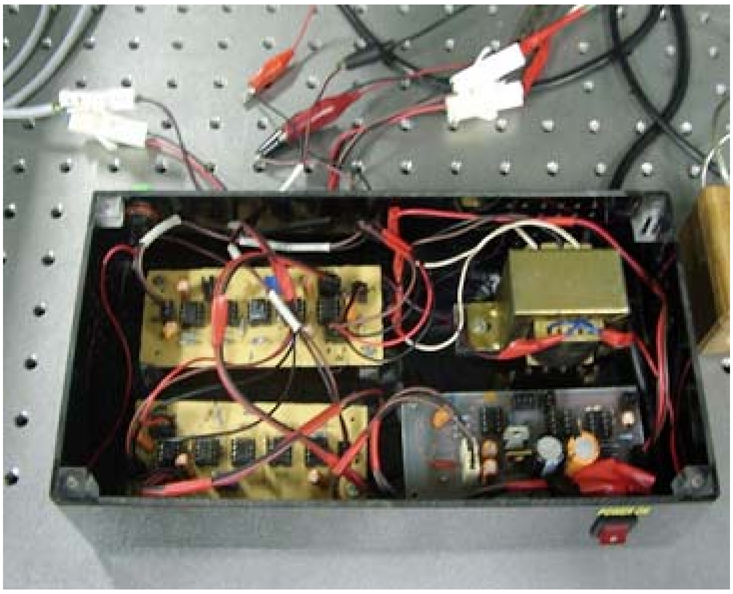

Fig. 2. Layout of the developed hardware setup.

2.2. Subjects

A total of 30 subjects (11 female, 19 male) were involved in the study. Each subject was informed about the details of the study and their verbal consent was taken before the recordings were made. Subjects were divided into two age groups 20-35 years (22 individuals, further referred to as Group 1) and 38- 61 years (8 individuals, further referred to as Group 2). Peripheral pulse measurements were recorded for 10 sec with the subject sitting on a chair and the arm positioned at heart level with the forearm resting on a table. Care was taken to see that the effect of motion artifact was the lowest possible. Subjects were also asked not to undergo strenuous exercise, avoid consuming hot drinks or those containing caffeiene and refrain from smoking for 2 hours prior to recording. It was also ensured that the subjects were relaxed and breathing regularly and gently.

2.3. Derivation of the Mean Pulse Function

The contour of the BVP exhibits an early systolic peak and a later peak or point of inflection that occurs a short time (ΔT_{BVP}) after the first peak in early diastole as shown in Fig. 3. The systolic component results from the direct pressure wave travelling from the left ventricle to the digit, and the diastolic component results from reflections of the pressure wave by arteries of the lower body back to the finger. The time between these two peaks (ΔT_{BVP}) is a measure of the transit time between the subclavian artery and reflection sites and has been used to define a noninvasive measure of large artery stiffness [6].

The PPG signals were recorded from the index finger of the right hand as there is evidence that differences between the age groups are more significant for the right hand compared to the left hand [1]. A program was written in MATLAB to determine a mean pulse function from the window of resting PPG data which was recorded over a period of 10 s. The set of measured pulses is optimized for contour similarity in order to minimize the effects of motion and damping artifacts normally present in such data. Also, normalization of the mean pulse function was performed for overall shape assessment and to get rid of variability due to heart rate differences [2, 7]. From this ensemble – averaged mean pulse ΔT_{BVP} was determined as the time between the first systolic peak and the early diastolic peak/ inflection point in the waveform. The peaks were located using the derivative of the mean pulse function. The systolic peak was identified as the first zero crossing and the subsequent negative zero crossing, or positive inflection nearest to zero determined the time of the diastolic peak or inflection occurrence. It is not necessary that in all the age groups the dicrotic notch be predominantly seen. In these cases the second peak is considered to be the point of inflection itself.

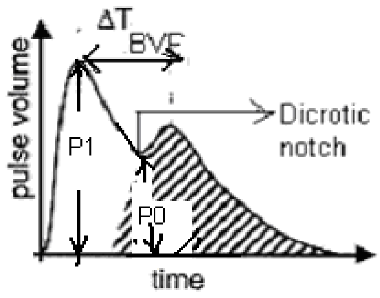

Fig. 3. BVP recorded by measuring the transmission of IR light through the finger pulp.

2.4. Age Related Indices Derived from the BVP Stiffness Index

Assuming the path length to be proportional to a person's height, the stiffness index has been defined as

$$S.I\ (m/s) = \text{Body Length}/\Delta T_{BVP} \quad (1)$$

Because of the complexities of the formation of the BVP, S.I cannot be considered as a direct measure of large artery PWV. It could be simply considered as an index characterizing the features of the contour of the BVP that are determined mainly by PWV in the aorta and large arteries, and hence by the stiffness of these arteries.

Minimum rise time

The minimum rise time (MRT) parameter has been defined [8] as

$$MRT = dt/dy \times (\text{Maximum Pulse Height}) \quad (2)$$

This represents the inverse of the normalized maximum rate of rise of the blood pulse volume. The MRT values for each subject in the two age groups mentioned in the experiment were determined using the already derived mean pulse function.

P_0/P_1 Ratio

The systolic peak of the recorded BVP was located and the valley point was used to locate the dicrotic notch. From the derived mean pulse, the foot of the BVP waveform was located and was taken as the reference. The ratio P_0/P_1 was calculated as the ratio of the amplitude from the foot to the valley point to the amplitude from the foot to the systolic peak [9].

All the three indices were derived from the mean pulse function.

3. BVP Analysis

The waveforms were analyzed offline using MATLAB and Origin 7.0. Anomalous pulses due to movement or irregular breathing were eliminated from the analysis. From the recorded BVP signals the foot to peak amplitudes and foot to valley point amplitude were determined. Also the time difference between the systolic and the diastolic peaks were calculated. The values of S.I and MRT were calculated using equations 1 & 2.

Pulse shapes for normal healthy subjects have been analyzed. Characteristics of the pulse shape for three different ages are shown in Fig. 4.

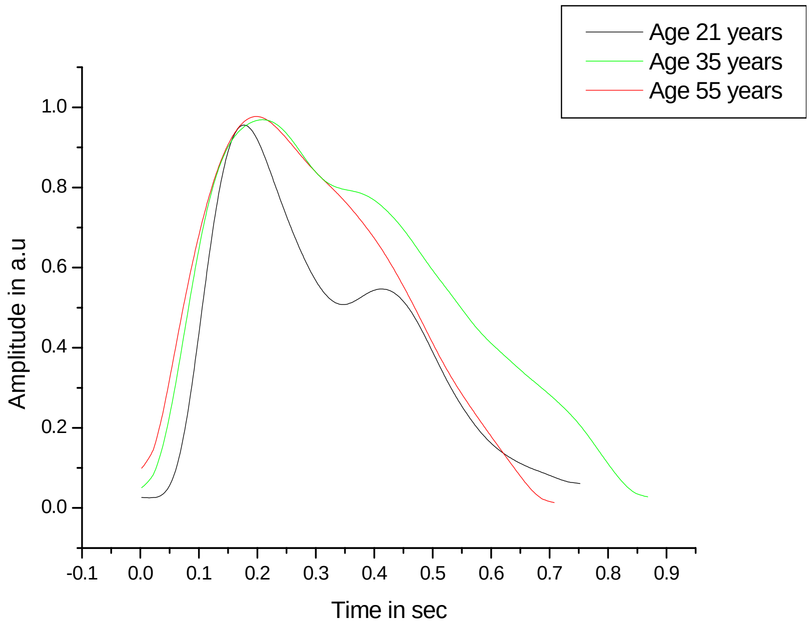

Fig. 4. Mean pulse shape for subjects aged 21, 35 & 55 years.

It is clearly seen that the pulse contour exhibits changes in shape with respect to the systolic slope and the demarcation of the dicrotic notch. Figures 5, 6, 7 show the variation of MRT, P_0/P_1 and S.I with age respectively.

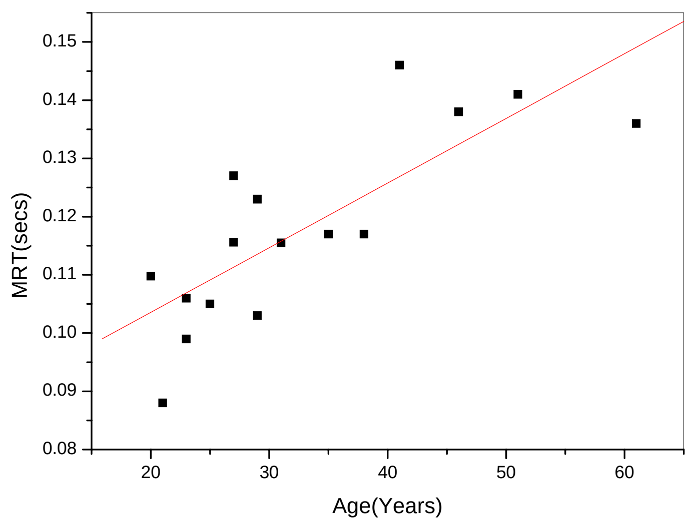

Fig. 5. Variation of Minimum rise time with age.

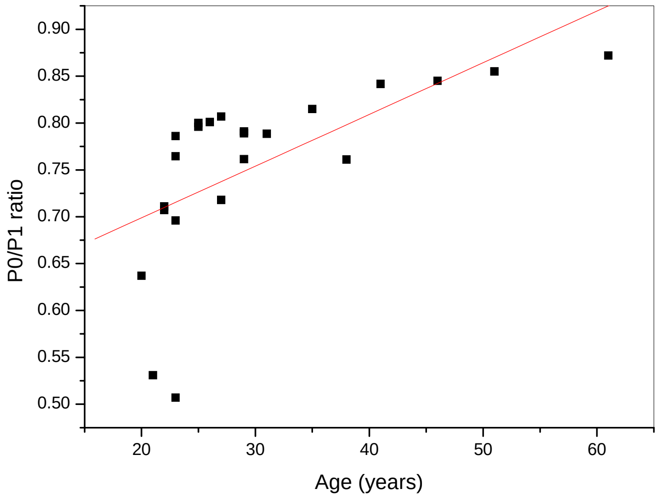

Fig. 6. Variation of P0/P1 ratio with age.

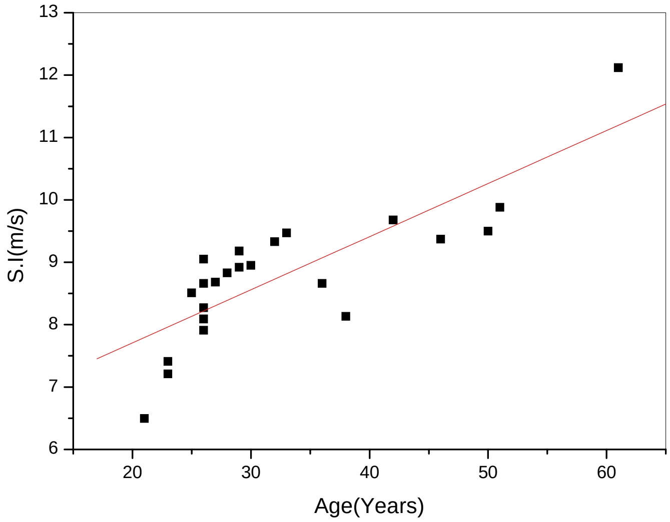

Fig. 7. Variation of Stiffness Index with age.

Results and Discussion

The parameters of contour analysis under investigation, MRT, S.I & P_0/P_1 ratio are derived from measures of distinctive portions of the BVP, the systolic and diastolic regions, respectively. As seen in Figs. 5, 6, 7 the older group is found to have all the parameters higher compared to the younger group (group 1). This agrees well with the studies conducted earlier [1, 3-4]. All the earlier reported works in literature have been carried out with commercially available equipments whereas in our work we have used the hardware setup indigenously developed in our laboratory [5]. The reproducibility of our measurements and the agreement with those done using commercial equipments highlights the usefulness of our system. Moreover, our setup is cheap from the economic point of view since we have made use of locally available components. The PPG acquisition system that we have developed is light in weight and hence portable in nature.

In older subjects, the pulse can become smoothed, with changes in the blood pressure pulse producing less dramatic changes in the blood volume pulse at the periphery [10]. The results show an overall elongation of the systolic rising edge, which could be explained on the basis of changes in resistance & compliance properties of arteries with advancing age. The diminishing of the dicrotic notch in older subjects (group 2) can in part be attributed to age related increases in PWV resulting in a faster reflected wave augmenting the forward wave.

Conclusion

Our analyses had shown the overall trend of changes in pulse shape characteristics with advancing age in a normal study population. In older subjects, the arteries are less distensible, leading to high PWV thereby resulting in a more rounded BVP with a lack of the dicrotic notch. The three parameters that we have determined can provide a simple noninvasive means for studying changes in the elastic properties of the vascular system. The obtained results demonstrate that the overall effect of changes in arterial properties, such as relating to arterial stiffness, can be detected non-invasively from the finger tip by examining the BVP shape characteristics. Further tests in a clinical environment are necessary, based on age-matched normal ranges of pulse characteristics which will help highlight when a patient's pulse falls clearly outside a normal range. This will be especially applicable when evaluating pulses from patients with possible vascular diseases.

Acknowledgement

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