Original

Quantification the Effect of Ageing on Characteristics of the Photoplethysmogram Using an Optimized Windkessel Model

Doostdar H.[1], Khalilzadeh M. A.[2]*

[1]Department of Biomedical Engineering, Mashhad Branch, Islamic Azad University, Mashhad, Iran
[2]Department of Biomedical Engineering, Mashhad Branch, Islamic Azad University, Mashhad, Iran

ABSTRACT

Background: With increasing age, some changes appeared in specifications of vessels which including dimensions and elasticity in theirs. The changes in parameters such as resistance, inertance and compliance vessels appear and eventually changes in the environmental pulse releases are in circulation. These changes clearly appear in specification of photoplethysmogram particularly in the size and position signals second peak is observed.

Aim and scope: The aim of study was to Circulatory system modeling using windkessel electrical model for evalution blood flow and Its matching with the photoplethysmogram's signal for investigate the reasons for changes of Characteristics of the Photoplethysmogram. The first purpose of this paper is to examine the age-related parameters in the Photoplethysmogram's signal and finally the diagnosis of cardiovascular disease using the model and photoplethysmogram's signal.

Methods: In this study we followed some of these effects to the circulatory system by using the windkessel electrical model. The algorithm in this project appeared by optimization with the matrix coefficients of state space windkessel electrical model. Optimize of the coefficients matching with the output of the model and the photoplethysmogram's signal. Photoplethysmogram's signals from 50 healthy subjects with the age range of 20 to 50 years, shows that outputs the model and photoplethysmogram's signal in terms of error rate and cross-correlation algorithm in a fully automate, was consistent. Wavelength of the Photoplethysmogram's signals were 950 nm and The sampling rate was set at 50 Hz.

Results: Simulation results show that aging reduces the signal amplitude and delay of the second peak occurs. These changes were seen as reduce the rate of compliance and increase the rate of resistance and inertance windkessel electrical model of circulation.

Conclusion: The high accuracy of the results led to being able to identify the age range and some cardiac arrhythmias in individuals. All the simulations were done in matlab software environment.

Keywords
Photoplethysmogram(PPG), Quantification, Windkessel's electrical model, State space variable

Introduction

We can model circulation systems in order to find the parameters of pressure, flow and blood volume. Among the variables that are involved in the value of these parameters, we can point to the dimensions and elasticity of vessels, fluid density at standard conditions and viscosity of vessel [1]. For better analysis of the cir-

*Corresponding author:
Khalilzadeh M.A.,
Department of Biomedical Engineering, Mashhad Branch, Islamic Azad University, Mashhad, Iran
Email: makhalilzadeh@mshdiau.ac.ir

culatory system, we model the basic variables with electrical variables such as strength inertance and compliance (capacitance). Electrical model of the circulatory system is known to windkessel electrical model. This model was first performed by Frank who was a German physiologist in 1899 [2]. This simple model includes the Resistors and capacitors. Later approached for further research and data modeling with data obtained from physiological experiments, Burattini considering the elasticity of arteries an inductor added to the model [3]. Edmond Zahedi with an improved model could be very close to the actual data in 2007 [4]. one Of the variables mentioned above is compliant which is same as inverse of arterial stiffness, this variable is the most important parameter which effect on the release of peripheral pulses and blood flow as a structural; aging effect on arterial stiffness [5]. Arterial stiffness based on compliant can be defined as follows (eq 1):

$$C = \frac{dv}{dp} \qquad (1)$$

In this equation, dv is arterial blood volume and dp is arterial blood pressure. At a constant blood pressure, arterial stiffness depends on changes in blood volume that is associated with arterial thickness and radius [6]. With increasing age, thickness and radius of the vessel will change considerably, which leads to increased arterial stiffness and ultimately lead to gradual changes in volume of the elastin and collagen content of the arterial wall [7]. In recent decades much research has been done about the effects of aging on the cardiovascular system - the human vasculature. For these purpose invasive and noninvasive techniques have been used include the angiography, ultrasound, PPG &… [8]. According to the above photoplethysmogram (assessment of blood volume) associated with large eartery stiffness and can be used as a noninvasive, inexpensive, easy way and it gives us important

information on peripheral arterial pressure and increasing age. The LRR is known PPG as a non-invasive use of non-visible infrared light beam to the skin [9]. The blood volume in the skin and tissue, infrared light is absorbed. We can be observed the changes in blood volume by measuring light absorption. We can see Blood volume and heart rate changes through the vascular system [10]. PPG signals measured between the domains and the pulse of a peak to peak at different wavelengths and its dependence on the optical absorption features of human blood provides information on health status [11,12]. Based on statements photoplethysmogram machine invented by Musu from Turin, Italy in 1870 ;it was reputation Polysmotography in Italy and it was published for the first time in the Journal of American Scientists in July 1872 [13]. Hertzmen, Spealman and Matthes introduce theory which show that changes in blood levels can be assessed and measured with light of transmission in the finger in 1930 [14]. The above changes in professional photoplethysmogram signal are intimately linked with changes in arterial compliance. In this paper we present an improved model and a new algorithm to optimize the model parameters were much closer to the actual data. Primary goal of this modeling is: having quantified between age & photoplethysmogram's waveform signal and the ultimate goal was presented system detect age and some Cardiac Arrhythmia by using signal PPG and model and algorithm which presented Submitted article.

Materials and Methods

In this study, at first we sign up photoplethysmogram's signal 50 healthy subjects. In the next stage of the Circulatory system was model with a 13-element & improved windkessel electrical model. Electrical model of the circulatory system in the next stage in the heart of every subject in the software simula-

tion was Simulink and finally, using a fully automated algorithm in state space model of programming content matrix coefficients based on solidarity and mutual windkessel electrical mode signal error rate was optimized for each individual photoplethysmogram.

The recorded signal

Photoplethysmogram's signals were recorded from 50 healthy subjects (30 men and 20 women) ranged in age from 20 to 50 years. Signal is recorded using non-invasive method was based on infrared. We use Wavelength of 950 nm in this method and transmission mode was recorded through their fingers. We was chosen translation method because it has lower noise than the reflection mode. For digitizing and storing the data in the computer system was used Power Lap, thus the text format by software CHART saved data in the computer. The sampling rate of the Photoplethysmogram's signals was set at 50 Hz. Then the signal for processing and later work was enter to content area. To eliminate noise in the signal contains artifact motion and rhythm of breathing and high frequency noise of power in city we passes signal through band pass filter (.2 - 30 Hz) . we tried to use filter without Phase delays or distortion in the signal. Signal recorded in aquasi-clinical environment with a temperature of 20°C was performed. The registration period lasted a minute and people were asked to state that any type of food And drink eat affects blood vessels and also the record of 2 hours before exercise and avoid smoking [8]. Photoplethysmogram wave form signal depends on temperature conditions, including human breathing, physical activity and cardiovascular system. The purpose of this paper is to examine the age-related parameters, so as possible other parameters affecting the signal photoplethysmogram were removed. For better analysis, the Photoplethysmogram's signals was normalized to X(t) so that all values were within the range (0,1). Data normalization defined as follows (eq 2):

$$X(t) = \frac{PPG - PPG_{min}}{PPG_{max} - PPG_{min}} \qquad (2)$$

where PPG_{max} and PPG_{min} are the maximum and minimum values of Photoplethysmogram's signals.

Windkessel electrical model

Windkessel electrical model is used to simulate many human circulatory systems. This model described the relationship between aortic blood flow and aortic blood pressure in the human vascular system [7]. Among these models we can pointed out to Frank's model which was published in1899. This model includes a Resistors and capacitors. Later Burattini was complete the model by adding a parallel resistance and capacitance. Burattini later added an inductor in series with the resistance, to the model to consider the inertia of blood flow. We used the Model which has complete matching with photoplethysmogram signal from the finger. This model, respectively gain the addition of blood back to the Edmond Zahedi's model which was published in 2007. This model consists of 5 parts in the table 1 is shown:

Table 1: Arterial system segmentation

Anatomical components	Arterial segment
Aorta	A
brachial(the arm)	B
Radial and ulnar	C
Capillaries	D
The return of blood to the heart	E

In this study each of the circulatory system sin the above table has been modeled with the Burattini's model. Finally; we gained an improved windkessel electrical model with 13 elements. Figure 1 is an electric model which is simulated in software Simulink content.
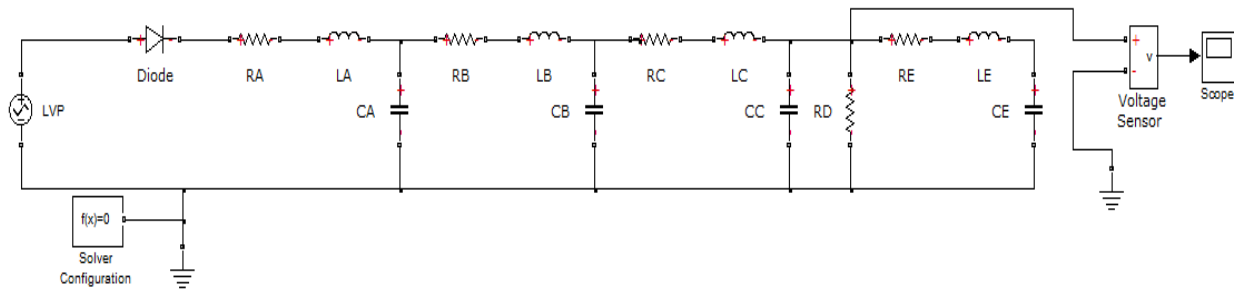
Figure 1: Modified 13-elements Windkessel model

For modeling Left ventricular pressure we used a variable frequency sinusoidal and some other element including diodes, inductors, capacitors and resistors. This resource was based on the frequency and duration of systolic and diastolic heart of every individual [15]. Note that the left ventricular pressure signal was very important in optimizing the parameters of this model, we tried the signal is much closer to reality. Figure 2 Example of left ventricular pressure in a subject shows:
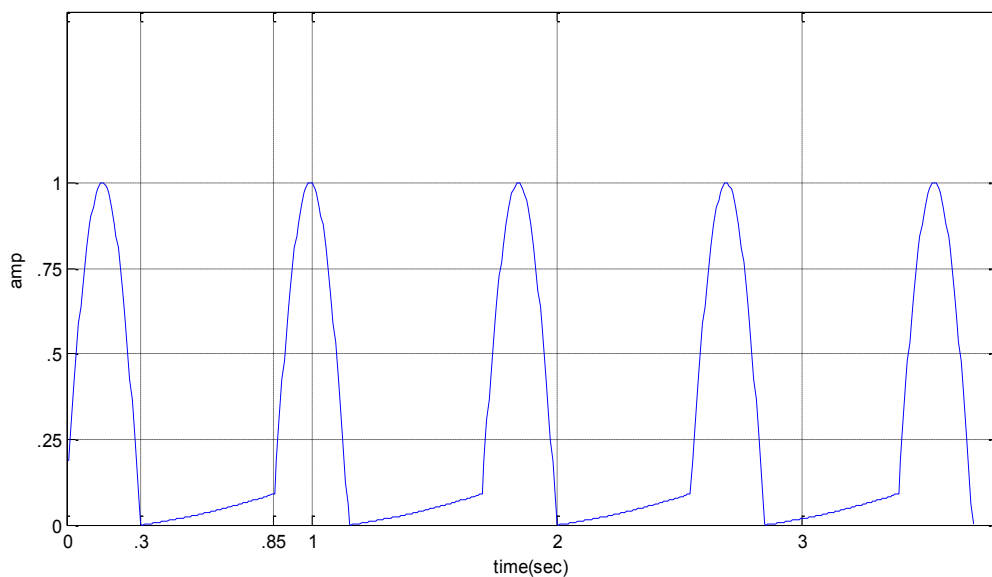
Figure 2: Example of left ventricular pressure in a subject

The optimization algorithm

To adjust the model parameters and the implementation of photoplethysmogram we were used fully automatic algorithm in the MATLAB programming environment. Based on this algorithm, first we designed input source that was related to left ventricular pressure, with the heart rate and systole and diastole time of each individual. Then based on previous studies we change the parameters of the model in a certain range, so the output model was obtained. Then the output model is compared with photoplethysmogram signal of each person. This compares was performed with the cross-correlation between signal and error rates (difference between model output and the signal photoplethysmogram). Finally, if these two criteria were more or less of experimentally obtained in the experiments final decision would be taken. According to above if the output of model was matched with a PPG signal; the algorithm terminates, otherwise the algorithm is repeated and the parameters were set again. Block diagram of the algorithm are in figure 3:
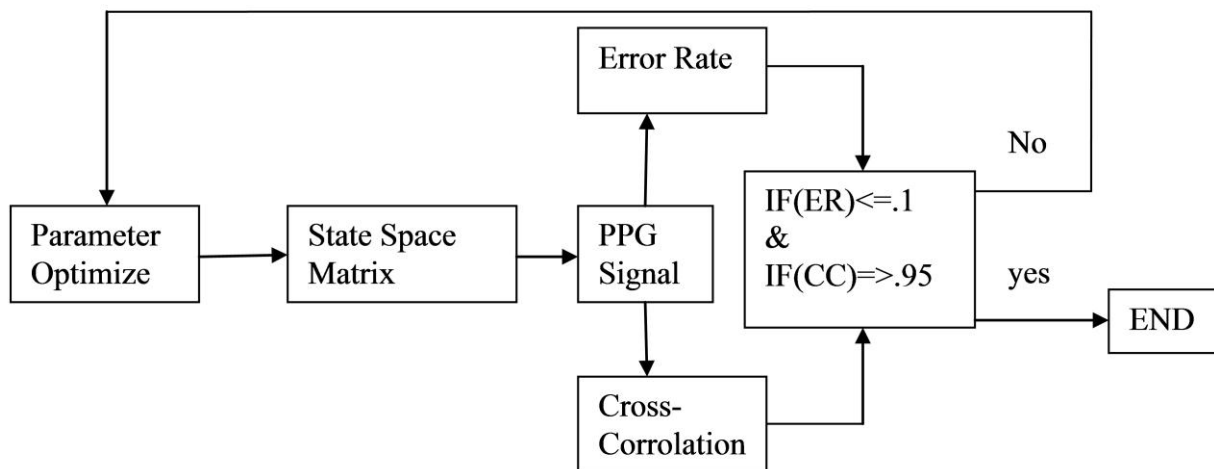
Figure 3: Block diagram of the algoritm for the automatic optimization of state space variables of the Windkessel's electrical model.

Results

Photoplethysmogram signals recorded from 50 subjects were ranged in 10 age groups. The age groups were selected based on age. Age group (21-23) years, (24-26) years, (27-29) years, (30-32) years, (33-35) years, (36-38) years, (39-41) years, (42-44) years, (45-47) years, (48-50) years. For each age group by using the algorithm windkessel electrical model was optimized. After optimal the matrix coefficients of the state-space windkessel electrical model, these coefficients to the numerical value of inductance, capacitance and resistance, which became part of the model parameters. Figure 4 is shown the output of the model after optimized the parameter with PPG signal for five age groups. Numerical results of the model parameters optimized for the 5 age group are in table 2:

Table 2: Optimized parameter for 13-element Windkessel model

Arterial segment	A			B			C			D	E		
Parameter	RA	LA	CA	RB	LB	CB	RC	LC	CC	RD	RE	LE	CE
	Ohm	Hanry	Farad	Ohm	H	F	Ohm	H	F	Ohm	Ohm	H	F
Group													
21-23	0.85	5.2	460	1700	70	120	2800	650	22	2.8	6200	110	760
27-29	0.85	5.2	410	1760	72	96	3250	710	19	2.8	7200	126	610
36-38	0.9	5.8	310	2720	83	78	5600	820	18	2.9	7950	160	480
42-44	1.2	6.2	160	3960	89	40	8200	890	9	3.1	9800	198	320
48-50	1.2	6.3	80	4850	96	29	9960	920	4.3	3.2	11200	210	301
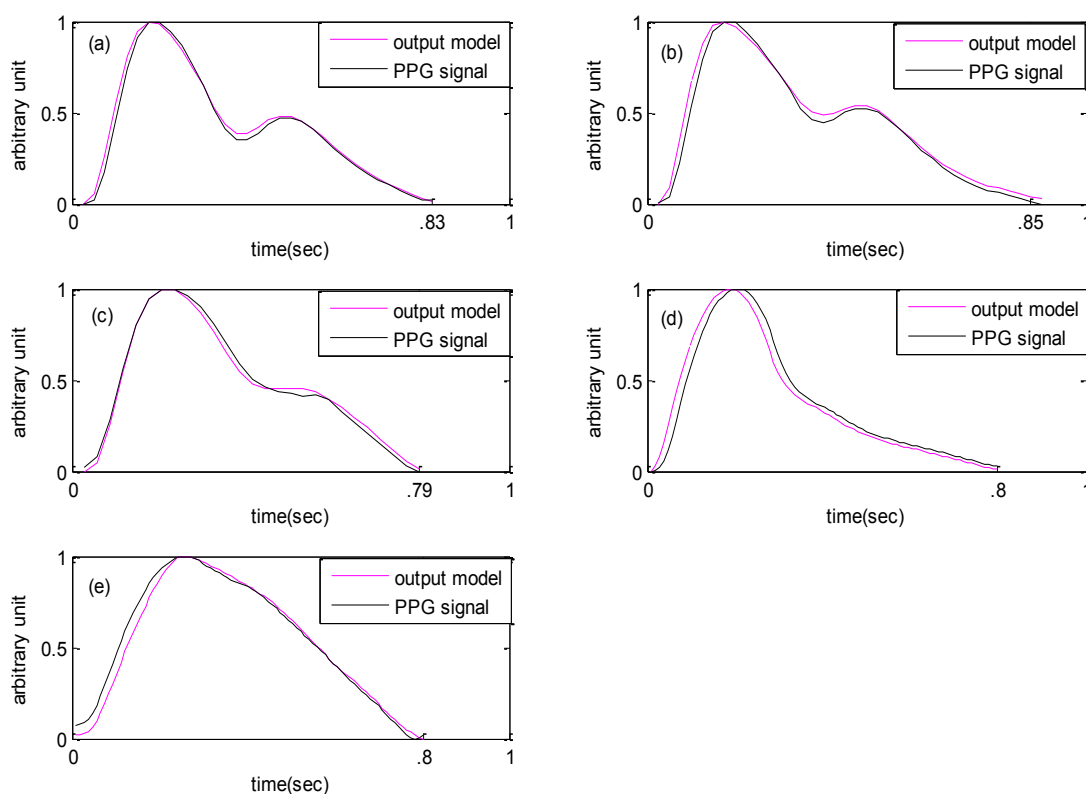
Figure 4: Recorded PPG and simulated PPG signal from a 13-element Windkessel model for a subject aged: (a) 21 years; (b) 28 years; (c) 37 years; (d) 43 years; (e) 50 years

Discussion

In this study we sought to quantification photoplethysmogram signal by using windkessel electrical model and improved it with 13 elements. PPG signal reveals Changes in regional blood volume of the tissue. We can be achieve, a lot of information about the circulatory system with this survey, blood volume and high correlation with arterial compliance [7]. This information can help us to identify the effects of aging and diseases [11,12]. Results from the signals recorded in the age range state din the paper showed that with increasing age and a reduction in peak amplitude of the signal delay occurs in the second peak of PPG. The reason for the decrease in systolic blood vessels increase in diameter and it is older [16,17]. This study showed that increase in vascular resistance and compliance inertance and reduction in the rate model will be associated with the circulatory system. The results of this study have very high accuracy because we tried the left ventricular pressure is very close to the reality. Also the optimization algorithm presented in this study calculated the model parameters with high accuracy by that we can be identified the age and some cardiac arrhythmias in individuals. For diagnosis Age range of individuals, after modeling and optimization of model parameters, a second signal was given to determine the age and arrhythmia detection algorithm, so with high accuracy, we could identify the age and diagnosis on the presence of cardiac arrhythmias. This algorithm was founded on the model output is optimized for an age range of the signal in individual ppg was adapted in the same age group. Accordingly, we can identify some cardiac arrhythmias such as aortic stenosis was present in two individuals. It was determined that if the signal was consistent with age and the age range was higher than it was diagnosed. In this study Diagnostic threshold was considered as a pilot for 10 years. This thresh-

old was identified two subjects, who had aortic valves tenosis. The correct diagnosis was made according to a cardiologist. Finally, we need more research in this area, but we can find that a system designed could help us to diagnose some cardiovascular diseases based on noninvasive photoplethysmogram method.

Acknowledgments

Conflict of Interest

None

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