

Arterial Stiffness Detection Depending on Neural Network Classification of the Multi-Input Parameters

Firas Salih, Luban Hameed, Afaf Kamil, Armin Bolz

Abstract—Diagnostic and detection of the arterial stiffness is very important; which gives indication of the associated increased risk of cardiovascular diseases. To make a cheap and easy method for general screening technique to avoid the future cardiovascular complexes, due to the rising of the arterial stiffness; a proposed algorithm depending on photoplethysmogram to be used. The photoplethysmograph signals would be processed in MATLAB. The signal will be filtered, baseline wandering removed, peaks and valleys detected and normalization of the signals should be achieved. The area under the catacrotic phase of the photoplethysmogram pulse curve is calculated using trapezoidal algorithm; then will be used in cooperation with other parameters such as age, height, blood pressure in neural network for arterial stiffness detection. The Neural network were implemented with sensitivity of 80%, accuracy 85% and specificity of 90% were got from the patients data. It is concluded that neural network can detect the arterial STIFFNESS depending on risk factor parameters.

Keywords—Arterial stiffness, area under the catacrotic phase of the photoplethysmogram pulse, neural network

I. INTRODUCTION

THE cardiovascular diseases are the most fatal diseases in the world, accounting for 29.3% of deaths recorded in the WHO's World Health report in 2004[1]. To prevent and cure the diseases, it is important to diagnose the early stage of these diseases. Numerous studies had proved that the arterial wall stiffness is closely related to the cardiovascular diseases and therefore it is necessary to measure and evaluate the arterial stiffness for diagnosing the cardiovascular diseases. The recent years have therefore seen a focus in developing techniques to facilitate early identification of individuals at increased cardiovascular risk. In particular, there has been much interest in arterial stiffness measurement as a method of detecting cardiovascular changes before the onset of established cardiovascular disease. Indeed, arterial stiffness is now recognized as an independent and significant predictor of cardiovascular morbidity and mortality and its application to every day clinical practice appears inevitable [2]. Increased arterial stiffness is one of the important markers of arteriosclerosis.

Firas Salih, Institute of Biomedical Engineering, Karlsruhe Institute of Technology, Karlsruhe, 76187 Germany (phone: +4972160844615; e-mail: firas.salih@kit.edu).

Luban H. Hammed, Medical devices department, Electrical and Electronic Technical College, Baghdad-Iraq

Afaf M. Kamil, Senior Doctor in Ibn Alnafees Hospital, Baghdad-Iraq

Armin Bolz, Professor in Biomedical Engineering, Karlsruhe Institute of Technology, Karlsruhe-Germany.

The arterial stiffness is the major cause of the cardiac coronary ischemic disease and cardiac infarction [3]. The necessity for cheap, non invasive and accurate method for general screening of the patients for the arterial stiffness was raised in the recent years. Photoplethysmogram is simple device and low cost optical technique that can be used to detect blood volume changes in the microvascular bed of tissue, the photoplethysmogram had increasingly used since it was invented, it is now popular due its cheapness, noninvasivity, easily to use and operate [4].

The fingertip photoplethysmograph expresses changes in the volume of blood in the fingertip as pulse waves; providing information on beats of aortic origin, characteristics of the vascular system, properties of peripheral vessels, and the state of blood flow [5].

The PPG waveform comprises of pulsatile (AC) physiological waveform attributed to cardiac synchronous changes in blood volume with each heart beat, is superimposed on slowly varying (DC) baseline with various lower frequency components attributed to respiration, sympathetic nervous system activity and thermoregulation [4].

The photoplethysmogram AC pulse waveform can be divided into two phases, the anacrotic phase which is the rising edge of the pulse, were this phase concerned with systole. The catacrotic phase which is the falling edge of the pulse concerned with the diastole and wave reflection from the periphery [6].

The Photoplethysmogram naturally contains respiratory component and is reflected on the baseline and signal amplitude. PPG contains fluctuations caused by the enormous baseline drift and wandering followed by physiological condition and movement. PPG contains fluctuations caused by the respiratory and sympathetic activity, these artifacts should be defined and removed for better detection of the PPG signal [7]. An artificial neural network (ANN) is a flexible mathematical structure which is capable of identifying complex nonlinear relationships between input and output data sets. ANN models have been found useful and efficient, particularly in problems for which the characteristics of the processes are difficult to describe using physical equations. The neural network sets the input and multiplied by weights which look like factors of each input. The weights were set to random values originally which then optimized using the training algorithm. The neural network used feedback propagation for the training of the neural network and also for the reducing the errors in the output. A structure of mathematical units (neurons) is constructed; each neuron calculates the sum of its inputs and uses an activation function for its output.

The neurons are connected by weights that are adjusted in a training process, aiming at minimizing the network error function, in the training process; the backward propagation algorithm is often used. The main advantage of a neural network is the possibility to generate a complex decision boundary without full knowledge of the statistical properties of the data under observation [8].

II. METHOD

The Photoplethysmogram device based on the transmission of light through the fingertip according to Lambert-Beer law was used as measurement tool, the device was built using LED at wavelength 640 nm, the sampling frequency 250 Hz, and 12 bits resolution. The data were collected in echo and Ultrasound unit in (Ibn Alnafees hospital,Baghdad-Iraq) from patients who goes through the Doppler and echo ultrasound, the subjects were at rest for 10 minutes before the test and the subjects were laid on the bed in supine position ,the photoplethysmogram signal were taken from the right index finger , the blood pressure and the heart rate were also measured using Digital sphygmomanometer (Beurer BM16, Beurer GmbH). The other information like age, height,weight,pervious history of diabetus,hypertension,and other cardiovascular diseases were also collected. Excluded the data from subjects who taken beta blockers medication .The echo tracking method was used for diagnosis of the arteriosclerosis patients. The number of subjects the data were collected from them was 70 (53 male and 17 female) as shown in Table I. Informed consents from all the subjects were received to use their data. The photoplethysmogram signal were acquired by DAQ card (data acquisition card, National Instruments Inc), and displayed on the computer using Labview (NI,inc). The photoplethysmogram signal were measured from the right index finger of each subject and the length of each waveform is 60 s, it had chosen only the best 10 seconds of it, as shown in fig. 1. The signal was filtered using second ordered low pass filter at cutoff frequency 5 Hz for high frequency noise removal. A high pass filter was used later with cutoff frequency of 0.33 Hz to remove the low noise frequencies which appeared on the signal due to the breathing and the muscle movements and other low frequencies from the body. Then the signals were stored in the computer for further offline processing. The data were read in MATLAB (mathworks,inc) and the signal gone in series of processing ,firstly signal's peaks and valleys were detected depending on zero crossing points for the first derivative of the signal, then the signal entered into a algorithm for the baseline wandering which removes the breath effect and motion artifacts. The signal undergo through polynomial curve fitting which use different polynomial function to fit the valleys of the pulses, the curve passes through the valleys of these pulses in each segment. Then the fitted baseline drift subtracted from the original signal. This is very necessary to remove the effect of breath rhythm on the PPG signal.

Then signal went into the normalization procedure to normalize the amplitude and the width of each pulse to be one to one in both width and height, as in fig. 2.

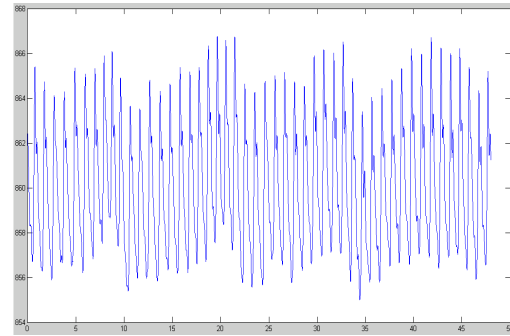


Fig. 1 Shows photoplethysmograph got in MATLAB

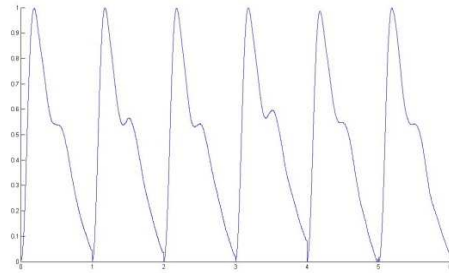


Fig. 2 Shows normalized photoplethysmograph pulses

The signal entered into area under the catacrotic phase (AUCP) calculations between the peaks and the next valleys,as in (1).

$$AUCP = \int_a^b f(x) dx \approx [b - a / 2n] \cdot [f(x_0) + 2f(x_1) + \dots + 2f(x_{n-1}) + f(x_n)] \quad (1)$$

TABLE I
DEMOGRAPHIC DATA FROM THE SUBJECTS

Parameter	Mean \pm SD
Age(years)	41.3 \pm 10.48
SBP(mmHg)	123.95 \pm 15.19
DBP (mmHg)	78.28 \pm 10.46
Height(cm)	169.76 \pm 8.7
Pulse pressure(mmHg)	45.67 \pm 10.46
Heart rate (/minute)	73.9 \pm 9.61
Male	53
Female	17
BMI(Body Mass Index kg/m ²)	24.22 \pm 2.86
NAUCP	0.36 \pm 0.0392

A. Neural Network Classification

The neural networks were set by using nine inputs these are: the normalized area under the catacrotic phase of the photoplethysmograph curve [10], age,height,weight,systolic blood pressure ,diastolic pressure ,heart rate, gender, and smoking as in fig. 3 and 4. The gender was treated as logical a value either zero or one; for the male was considered as one and female was zero. The neural network uses the feedback propagation method for the training and adapting the neural networks. The feedback training was changing the weights each time. The transfer function used is the sigmoid function because it is more suitable for a binary output. The neural

network is very powerful tool in the classification of these parameters.

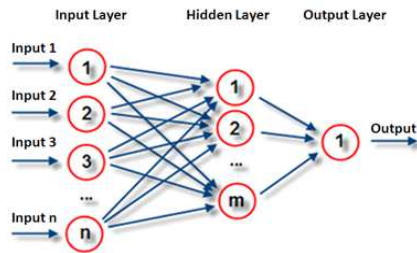


Fig. 3 Shows neural network propagation

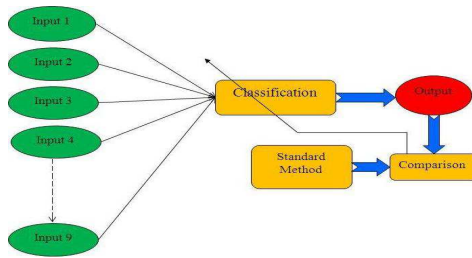


Fig. 4 Shows neural network for classification of the inputs

The training algorithm, used in this research, has been the back propagation (Back Propagation) as a method of adjusting weights in a forward network with one layer of trainable connections, and therefore very suitable for training perceptrons. The program was written in Matlab (Mathworks,inc) for creating in a network with random values of weights, so each time it is trained, the final values of the weights are not the same and it doesn't takes the same time to be trained. A loop has to be implanted that allows having a maximum of iterations for train the network. If in this limit the network does not reach their desired values, a new network is created and subjected to the same criterion. When the desired output is got, the network will be valid. Arterial stiffness can be defined by the following equations:

$$net = \sum_{i=1}^n \sum_{j=1}^j x_i w_{i,j} \quad (2)$$

$$Arterial\ stiffness = f(net) = \frac{1}{1+e^{-net}} \quad (3)$$

Equation (3) responds to the operation of a neural network with sigmoid transfer function. The results of the equation may vary between 0 and 1. The value 0 is no risk of arterial stiffness and the value 1 is risk. The program creates a neural network with the number of inputs, outputs layers that they are necessary. It is also necessary to indicate the training algorithm and transfer function of each layer. The neural network was created and trained in MATLAB (mathworks,inc) , the best results got with Cascade forward back propagation neural network which was created with num 1000 epochs ,10 neurons and two layers. Using the input values and corresponding output patterns, the instruction trains the network to get correct values in the output. The process of training a neural network involves tuning the values of the weights and biases of the network to optimize network performance, the default performance function for feed-

forward networks is mean square error (mse)—the average squared error between the network outputs and the target outputs .It is defined as follows:

$$Mse = \left(\frac{1}{N}\right) \sum_{i=1}^N (e_i)^2 = \frac{1}{N} \sum_{i=1}^N (t_i - a_i)^2 \quad (4)$$

III. RESULTS AND DISCUSSION

After the neural network was trained, the test set from 35 subjects was used for the neural network performance assessment by calculating the overall accuracy of the network and its ability to identify the normal subject from the patient. The accuracy, sensitivity, and specificity of the neural network are the important evaluation parameters of the neural network performance and show its ability to detect the patients from the risk factors. The accuracy of the neural network was as follows:

$$Accuracy = \frac{\text{Number of correctly Diagnosed Patients}}{\text{Total number of Subjects}} \quad (5)$$

The neural network sensitivity was as follows:

$$Sensitivity = \frac{\text{Number of correctly diagnosed patients}}{\text{Total number of patients with arteriosclerosis}} \quad (6)$$

The neural network specificity was as follows:

$$Specificity = \frac{\text{Correctly identified normal}}{\text{Total number of normal Subjects}} \quad (7)$$

Equations (5),(6) and (7) were applied to the test set data and the results were accuracy was 85%, sensitivity was 80% and the specificity was 90%. The MSE was 10^{-6} approaching the real identified values.

IV. CONCLUSION AND FUTURE WORKS

It was concluded that the neural network can be used for the detection of the arterial stiffness and other cardiovascular diseases from the analysis of risk parameters taken non invasively, these risk parameters can be measured easily, so it can be used in the future for general screening programs of the arterial stiffness and other cardiovascular diseases detection in the early stages of the diseases where the treatments are of benefits. The research is still under progress and further development will be made, large number of data will be used for training the neural network for reducing the errors and increasing the accuracy of the neural network in the detection of the arterial stiffness in the patients.

REFERENCES

- [1] World Health Organisation (WHO). The World Health Report 2004. 2004:120.
- [2] H. Hasegawa, M. Ozawa, H. Kanai, N. Hoshimiya, N. Chubachi, Y. Koiwa, "Evaluation of elastic property of the arterial wall by measuring small velocity signals using ultrasound", Ultrasonics Symposium, 1997. Proceedings, 1997 IEEE, Volume: 2, 5-8 Oct. 1997, Pages: 1169 - 1172 vol.2.
- [3] Avolio A, Jones D, Tafazzolo-Shadpour M " quantification of alteration instructure and function of elastin in the arterial media" Hypertension 1998;32(1):170-5

- [4] John Allen, "Photoplethysmography and its application in clinical Physiological measurement" *Physiol. Meas.* 28 (2007) R1–R39
- [5] Y. Iketani et al" Second derivative of photoplethysmogram in children and young people" *Jpn Circ J.* 2000; 64:110-116
- [6] Hertzman A B and Spealman C R "Observations on the finger volume pulse recorded photoelectrically" *Am. J. Physiol.* 1937, 119, 334–5
- [7] M.Nitzan,I. Faib,H. Friedman" respiration-induced changes in tissue blood volume distal to occluded artery,measured by photoplethysmography" *J. Biomed. Opt.* 11(2006)040506
- [8] Bernard Willers,Sep Verba" Neural Networks", ThinkQuest2000,project on Neural Networks,Team C007395,2000
- [9] Atkinson, Kendall E.," An Introduction to Numerical Analysis". (2nd ed.), New York: John Wiley & Sons, ISBN 978-0-471-50023-0, 1989.
- [10] Firas Salih, Qasem Qananwah,Omar Abdallah,and Armin Bolz" normalized area under catacrotic phase of the photoplethysmogram pulse for estimating vascular aging",9th international biomedical engineering , BioMed2012, Innsbruck-Austria, 2012