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# Blood Pressure Estimation Using Electrocardiogram and Photoplethysmogram

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## Abstract

An increasing number of people are suffering from cardiac diseases, diabetes, high or low blood pressure, and many more. There are many devices available in the commercial market to measure heart rate, blood pressure, and temperature of the human body. Old fashioned blood pressure meters are cuff based and inconvenient for daily monitoring. The aim of this project is to design a platform to optimally estimate blood pressure using electrocardiogram (ECG), photoplethysmogram (PPG), Pulse Transit Time (PTT), wavelet transform and artificial neural network (ANN). This kind of blood pressure assessment may not be satisfactorily correct because the regulation of blood pressure inside the human body is complex, multivariate biological procedure. Predefined data is used to get ECG and PPG. 70% data is used for training and 30% data is used for testing in ANN to get accuracy of the system.

***Keywords:*** ***Electrocardiogram (ECG); Photoplethysmogram (PPG); Wavelet Transform (WT); Blood Pressure; Artificial Neural Network (ANN)***

## 1. Introduction

Diabetes and high or low blood pressure are the key phases of foremost diseases. ECG, PPG or Pulse Graph, and Blood pressure are three key vital signs of the human body. To notice hypertension (associated to strokes and heart failure), a blood pressure reading is essential. High blood pressure also causes blood vessel damage and kidney failure [4] Heart rate is the number of times your heart beats per minute (BPM).[3] The heart rate changes according to oxygen changes in various condition of subject. Normal heart rate is between 60 and 90.[3] The person who is doing exercise, his heart rate is more than 90. Electrocardiogram senses the electrical activity of the heart related with each cardiac cycle. It is a graphical representation of cardiac activity and represented as voltage versus time.[1] It is used to diagnose and assist in treating some types of heart disease and arrhythmias, define a subject's response to drug therapy, and expose tendencies or dissimilarities in heart function.[9] PPG uses infrared (IR) light to measure blood flow in human body. In this research PPG is taken from ECG leads to reduce the cost. The changes in blood flow in body can be detected by PPG sensor as changes in the intensity of light. The voltage signal from PPG is proportional to the quantity of blood flowing through the blood vessels.[9] A PPG has several components including volumetric changes in arterial blood which is associated with cardiac activity, variations in venous blood volume which modulates the PPG signal. PPG shows the blood flow changes as a waveform.[6] The heart preserves blood moving over the blood vessels by pumping. Arteries termed finer blood vessel, which takes away blood from heart and generate pressure on the artery wall.[5] Veins fetch back blood to the heart and also create pressure on veins wall.[5] Normally blood pressure measures over arteries. Blood pressure varies from moment to moment, and is affected by many factors including breathing, position of the body, exercise, sleep, medicines and alcohol.[6] High blood pressure may cause heart disease, heart failure, stroke, kidney disease or failure and eye problems. Blood pressure is restrained in systolic over diastolic way. For ordinary body, systolic pressure is less than 120 mmHg and diastolic pressure is less than 80 mmHg. In general blood pressure is the ratio of highest to lowest pressure generated on arterial wall. During the systolic pressure ventricle (one of the heart chamber) contracts and causes more pressure on the artery. In another way, when the heart chamber contracts and drives blood to the artery, it produces pressure on the artery wall which is called systolic blood pressure. Thus, systolic blood pressure is more than diastolic blood pressure. After contraction the heart chamber take its ordinary position and refills blood in the chamber. The pressure creates at that time in the artery which is called diastolic blood pressure. Therefore, during diastole the pressure is at its lowest. Main purpose behind this research is to design a platform which will measure heart rate, PPG (photoplethysmogram), ECG (Electrocardiogram) and blood pressure.

Recent advancement in science and technology has led to an unprecedented advancement in provision of technological solutions for the numerous problems facing mankind. Researchers are busy leveraging modern technology to provide better and improved solutions commensurate to the ever increasing demands.

In the research of IJET, an optical system was created to measure the blood pressure with the use of an IR light source and a luminosity sensor. In that research, the optical pulsatile method was used to gather pulse data from various parts of body. The optical data was then combined with the IR light source and the optical data was converted to M.A.P (Mean Arterial Pressure) and then to systolic and diastolic blood pressure.

A Future Electronics report states that blood pressure can be measured digitally with the use of extern al controller such as an Arduino, cuff, and a compressor. In this research, pressure was measured by the cuff using the compressor and read by the controller. Using the controller the researchers were able to display, reset, and deletes data.

Another study conducted by McMaster University of Hamilton states that the continuous systolic and diastolic blood pressure can be measured by combining the electrocardiography and photoplethysmography. Non-invasive sensors were used to measure heart rate, blood pressure, and body temperature. In this study, three different machines were used to measure the vitals.

A combined study of University of Pittsburg, USA and Beijing Jiaotong University, China is showing that blood pressure can be measured with combination of pulse transit time, R-peak interval in electrocardiogram and fingertip photoplethysmogram. Systolic and diastolic blood pressure can be measured through maxima and minima of arterial blood pressure.

In the present study, blood pressure is measured by ECG, PPG and PTT with the use of wavelet transform and signal processing. To check errors in the system neural network toolbox is used.

## 2. Methodology:

### 2.1. Problem Formulation

#### 2.1.1. Heart Rate

Heart rate is defined as beats per minutes. To formulate heart rate from ECG, number of RR intervals need to be find. Heart rate demonstrating is directly proportional to the appearances with change in blood volume.[2] To measure RR interval of ECG signal wavelet transform is used. In this research heart rate is measured as follow

$$HR = \frac{N0*60*fs}{N}$$

Where N0 = Number of Peaks,

Fs = Sampling Frequency,

N = Length of signal

#### 2.1.2. Blood Pressure

To measure the blood pressure, heart rate and PTT are defined. Based on the values of HR and PTT, blood pressure is estimated using the following equations.

$$BP = -\frac{2}{\alpha} * lnPTT + \frac{\ln\left(\frac{2r\rho LL}{hE0}\right)}{\alpha} \quad [12] \qquad \dots\dots\dots (1)$$

Where L is vessel length, PTT is pulse transit time response, $\rho$ is blood density, r is inner radius of vessel, h is vessel wall thickness, and E0 is zero pressure modulus of the vessel wall.[12] Whereas, $\alpha$ is the constant.

There are several physical features that stimulus cardiac output and BP, such as the blood volume, resistance of the blood vessels, and blood thickness.[12] BP is the product of cardiac output and marginal resistance.[12] When BP falls, the nervous system is motivated. In response, HR rises in an effort to increase cardiac output and the arterial walls contract to increase BP.[12] So, BP is directly correlated to HR. Therefore, BP approximation function is as follow. Here, $\alpha, \beta$ $and$ $c$ are constants.

$$BP = c + \alpha * lnPTT + \beta * lnHR + (\alpha\alpha * HR * HR + \beta\beta * PTT * PTT) \quad [12] \qquad \dots\dots\dots (2)$$

### 2.2 Proposed System

In this system clinical data is used to get ECG and PPG. ECG and PPG has frequency range of 0.5 Hz to 20 Hz so, high pass filter is designed for 0.5 Hz as well as, low pass filter is designed for passing the frequency lower than 20 Hz. RR interval can be found from R peaks in ECG signals, which will support to find heart rate and pulse transit time response of ECG and PPG. As, PTT and HR are directly proportional to the blood pressure so, if they increases, BP increases and decrease with them BP decreases. Lastly, artificial neural network is used to find the error of the system. In that, output of the system is compared with the predefined clinical blood pressure data to train a system and do estimations. Fig. 1 is presenting architecture of the system.

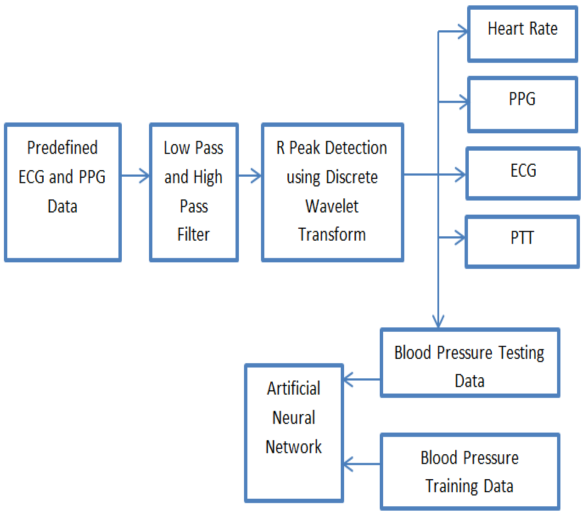


**Figure 1: Architecture of the proposed system**

### 2.3 Discrete Wavelet Transform:

In the discrete wavelet study the data stored in the wavelets coefficient is not constant; it allows the whole redevelopment of the original signal without redundancy. ECG signals compression techniques are important to enlarge storage capacity an improve methods of ECG data transmission.[11] DWT removes redundancy in the signal and provides a high compression ratio and high quality reconstruction of ECG signal.[11] DWT is a fast algorithm for machine calculation, similar as the Fast Fourier Transform (FFT); it is linear operation that operates on a data vector, transforming it into a numerically different vector of the same length. There is an even faster family of algorithms based on a completely different idea, namely that of multiresolution analysis, then the whole construction may be record into a pair of quadrature mirror filters, defined from the underlying wavelet function, and both are applied to the signal and down-sampled by a factor of two.[17] This process divides the signal into two parts, each of half the original length, with one containing the low-frequency information and the other the high-frequency information.[11] This process is repeated to get high and low components. DWT achieves a multiresolution decomposition of Xn on i octaves labelled by i = 1 to i. The condition for a multiresolution computation can be stated as follows:

$$hi + 1(n) = \sum_k hi(k) g[n - 2k] \quad [11]$$

The wavelets and ascending orders are obtained iteratively as one goes from one octave i to the next (i + 1). Finally the sequences are gathered and generate a discrete signal which can show the peaks of the signal.

### 2.4 Pulse Transit Time (PTT)

Pulse transit time (PTT) is the interval between ventricular electrical activity and peripheral pulse wave. It is assumed to be a replacement indicator for blood pressure changes. Pulse transit time is a likely, possibly useful key of arterial stiffness and cardiac output and has been proposed to be a substitute for continuous blood pressure measurement, particularly if not the absolute blood pressure values. PTT is defined as the time required for the arterial pulse pressure wave to travel from the aortic valve to border. It can be predicated as the delay between the peak of the R wave in the ECG and the arrival of the consistent pulse wave. PTT can therefore be easily measured, since only simultaneous recording of ECG and photoplethysmography are required.[17] For each subsequent PTT curve, a moving average curve with an interval of 20 s was created in order to fulfill the sample rate- and movement-associated noise.

### 2.5 Artificial Neural Network

ANNs are essentially enormous parallel computational models that replicate the function of human brain. An ANN consists of large number of simple processors linked by weighted connections.[18] Each node output depends only on the information that is locally available at the node, either stored internally or arriving via the weighted connections and each unit receives inputs from many other nodes transmits its output to yet another nodes.[18] It produces a scalar output with particular arithmetic value, which is a simple non-linear function of its inputs. An error is taken from the difference between the target response and the system output. This error information is fed back to the system and adjusts the system parameters in an efficient manner.

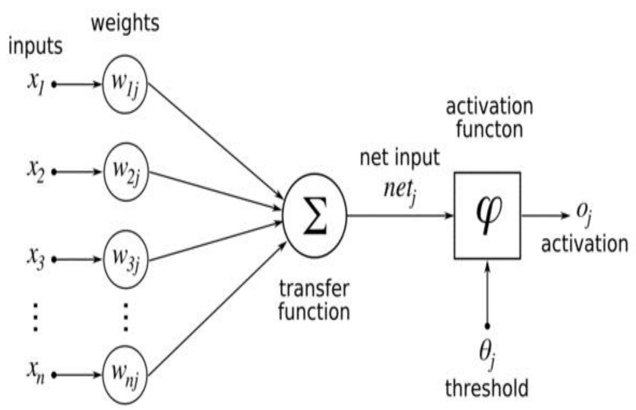


**Figure 2: Artificial Neural Network**[18]

From fig. 2 the interval activity of the neuron can be shown to be,

$$Vk = \sum_{j=1}^{p} Wkj * xj \quad [18]$$

The output of the neuron, Yk, would therefore be the outcome of some activation function on the value of Vk.[18]

## 3. Results

ECG, PPG, and blood pressure data from nine patients were extracted from physiobank which has data of $10*10^4$ samples. Fig. 3 shows the high pass and low pass filter output of the frequency range of 0.5 to 20 Hz simultaneously. Using those filtering methods, unwanted signals from the baseband signal can be removed.

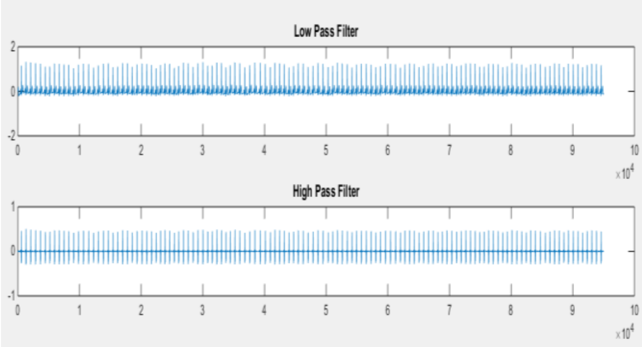


**Figure 3: Low pass and High pass filter output**

Wavdec function is used to formulate the discrete wavelet transform on ECG and PPG signals. From that peak's signal, an approximate 0.90 second RR interval can be found. Fig. 4 and fig. 5 show the peak detection of ECG and PPG signals simultaneously. $12*10^4$ samples are used to construct the signals. High gratitude of accuracy of the proposed system is particularly substantial because it is based on the wavelet transform method. However, earlier studies did not show high performances compared with non-wavelet transform-based methods.

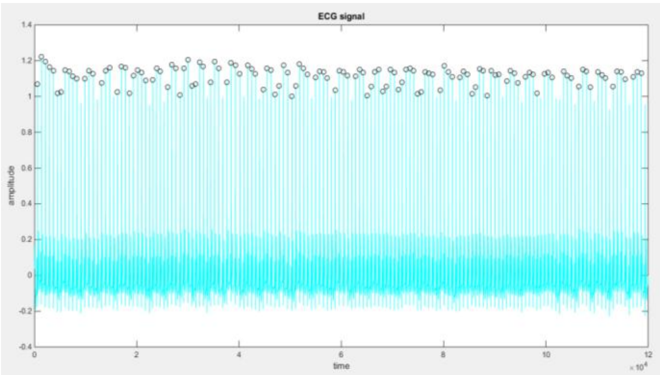


**Figure 4: R-peak detection of ECG**

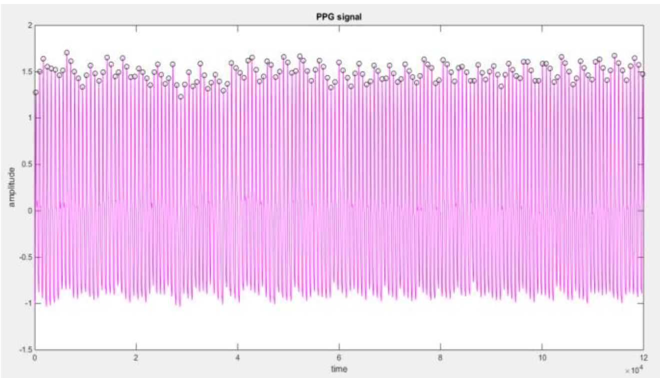


**Figure 5: Peak detection of PPG signal**

PTT is the consecutive time that a pressure pulse spends in transmitting through that length of the signal to detect the next upcoming pulse. PTT is directly proportional to the blood pressure. Fig. 6 displays the pulse transit time response of the ECG and PPG signal.

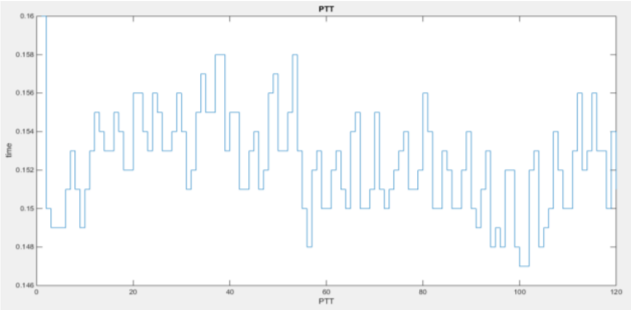


**Figure 6: Pulse transit time responses of ECG and PPG**

Twenty consecutive readings of the heart rate indicate that the average heart rate is 78.16 BPM; whereas, the systolic and diastolic blood pressures are 112.97 mmHg and 78.55 mmHg, respectively. The blood pressure is in the range of <120 mmHg and <80 mmHg. Thus, the estimated blood pressure is accurate. This kind of BP is accurate but it has certain limits as compared to blood pressure devices such as those used in professional medical settings. Fig. 7 and fig. 8 indicates the difference between actual and estimated blood pressure.

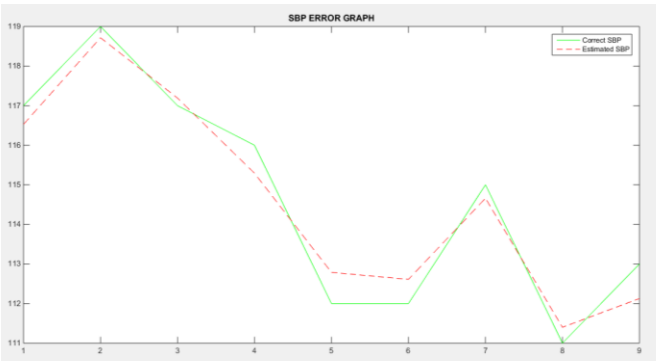


**Figure 7: Estimated VS Actual Systolic Blood Pressure**

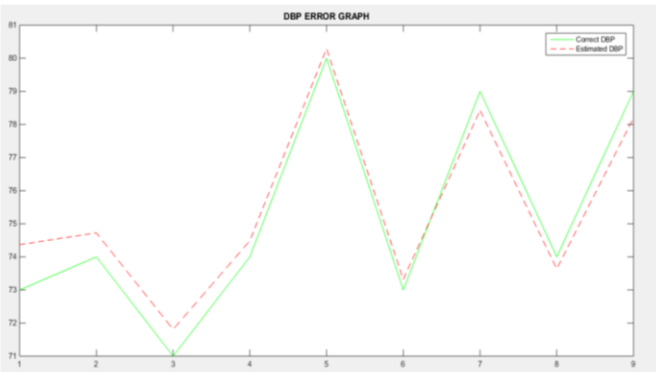


**Figure 8: Estimated VS Actual Diastolic blood pressures**

Classification of the predefined blood pressure and actual output is established by using a confusion matrix of ANN, showing an 83.3% accuracy level and a 16.7% error level. Fig. 9 is a visual representation of the confusion matrix of ANN.

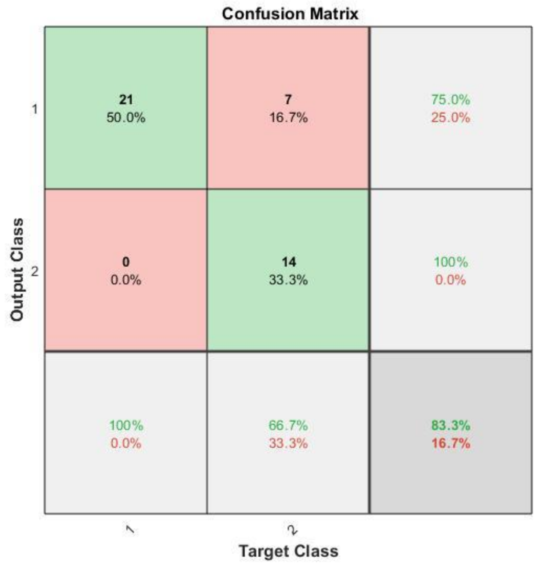


**Figure 9: Confusion matrix**

## 4. Conclusion

The proposed system was tested on clinical data of ECG, PPG and blood pressure. It successfully obtained the heart rate of 78.16 BPM, peak detection, pulse transit time response and blood pressure of by 112.97/78.55 mmHg. This System is also gave an 83.37% accuracy using artificial neural network.

## APENDIX A

**Background Information**

The Raspberry pi is a minicomputer with Raspbian OS that runs multiple programs concurrently; whereas, The Arduino is a microcontroller, which is a part of the computer that operates only one program at a time.

Furthermore, the Raspberry pi is difficult to connect to a battery pack, and it is costly. However, the Arduino can be powered using a battery pack and it is more economical than the Raspberry pi.

Moreover, the Raspberry pi is difficult to interface sensors and connectors; whereas, the Arduino is significantly simple to interface sensors and connectors.

The main reason for researchers to switch from the Raspberry pi to the Arduino is because live ECG, PPG and BPM will be used and it is only possible with the serial input-output port. Arduino has the serial port, and raspberry pi does not.

The results from this study explains that to formulate the signal processing in MATLAB, data must be saved and retrieved at any time therefore, predefined clinical data is used in this research.

**Heart Rate (BPM) using Raspberry Pi:**

Beats Per Minute (BPM) referes to how many times the heart beats per minute. The first picture shown below is the BPM of a person with a resting heart rate and the second picture is a BPM of a person who climbed stairs for five times. The pulse sensor converts the mecanical signal of the heart to the analog electrical signal and the AtoD converter converts the analog signals to digital and that digital signals transfers to the raspberry pi. The Rpi kit works on that signal as per the code in the Python and displays the heart beat on the screen. If the pulse sensor can not find the constant two pulses, then it shows “no beats” on the screen. The drawback of this sensor is that if we touch the sensor two inches below its head, then also it measures the pulse. The ADS has a built-in amplifier so that it shows a 99 to 104 pulse range for a normal person.

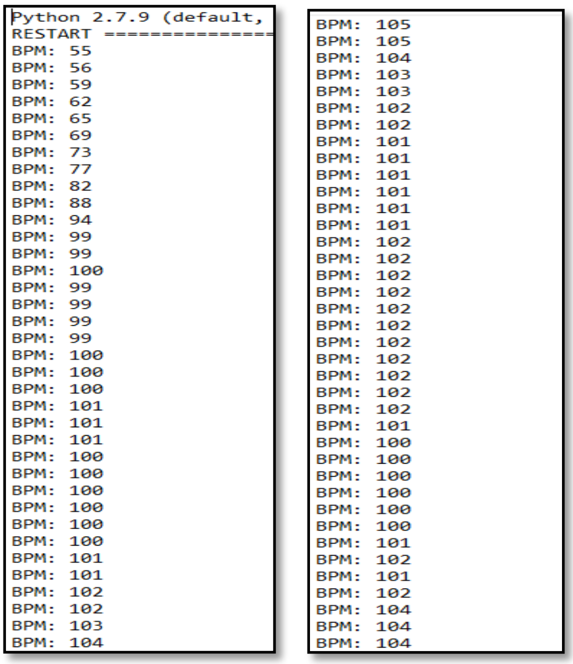


**Figure 10: Heart rate of raspberry pie**

**Flowchart for Pulse Graph (PPG)**

First to create a pulse graph, all variables will be initialized for input-output pins and write functions for serial communication such as baud rate and interrupts. Second, set interrupts and baud rate and I/O pins. The sensor will convert the mechanical signal to an electrical signal for each cardiac cycle. Third, the electrical signal will feed the controller, graphing the signal on the serial plotter and displaying the heart rates on the serial monitor.

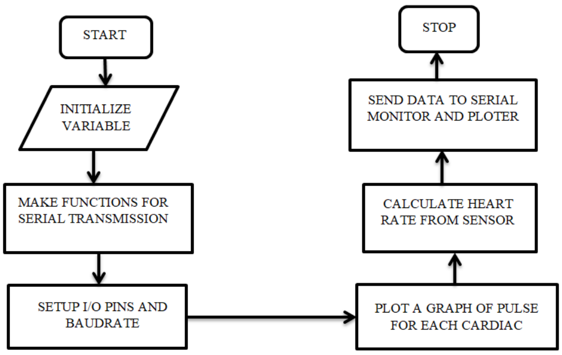


**Figure 11: Algorithm for PPG**

**Flowchart for ECG**

To obtain an ECG place three ECG leads on the left shoulder, right shoulder and left side of the stomach. Then connect those leads to AD8232. At the run time, first initialize the variables for I/O pins, baud rate, and interrupts. Second, send electrical signal to serial input, and also import the sketch to the program. Third, set the graph in a horizontal position and set the incremental points of each cardiac cycle. Finally when the signal reaches the end, it will automatically return to the beginning for the next cardiac cycle.

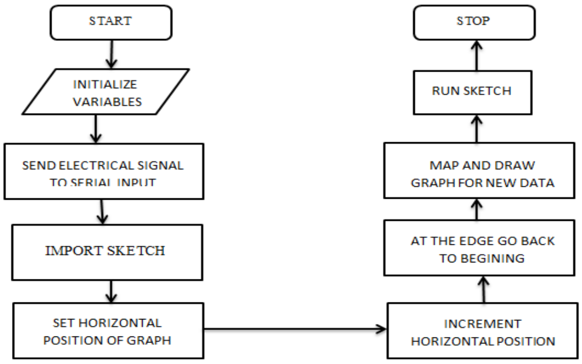


**Figure 12: Algorithm for ECG**

## References:

[1] “A New Data-Reduction Algorithm for Real Time ECG Analysis,” by Abenstein J. and Tompking W., IEEE Transactions Biomedical Engineering, vol. 29, no. 1, pp. 43-47, 1982.

[2] A Low Cost Optical Sensor Based Heart Rate Monitoring System byMohammad NasimImtiaz Khan, DewanFahim Noor, Md. JubaerHossainPantho, Tahmid Syed Abtahi, FarhanaParveen and Mohammed ImamulHassan Bhuiyan Department of Electrical and Electronic Engineering Bangladesh University of Engineering and Technology, Dhaka–1000,Bangladesh.

[3] Microcontroller Based Heart Beat Monitoring and Alerting System Mayank Kothari Assistant ProfessorNMIMS, MPSTMEShirpur, India, IOSR Journal of Electronics and Communication Engineering (IOSR-JECE) e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 9, Issue 1, Ver. I (Jan. 2014), PP 30-32 www.iosrjournals.org.

Development of a Wireless Blood Pressure Monitoring System by Using Smartphone, Dr.R.Harini, Prof. B. Rama Murthy, International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE) Volume 6, Issue 12, December 2017, ISSN: 2278 – 909X

[4] Infrared Sensor and Amplifier for Blood Pressure Monitor, University of Minnesota Department of Electrical Engineering, EE 4951 – Senior Design, by Yan Qu, Daniel Kuha, Zhongyu He, Shams Faruque Zi Huang, Spring 2012.

[5] Design of non-invasive techniques for blood pressure monitoring, by Bhushan Deshmukh, International Journal of Latest Trends in Engineering and Technology (IJLTET), ISSN: 2278-621X.

[6] Non-invasive Optical Blood Pressure Sensing and Measurement, Mr. Ketan Karambelkar #1 , Ms. Sanika Balkawade #2 ,Ms. Jagruti Kapgate#3 , Mrs. Kirti Adoni#4, International Journal of Engineering Trends and Technology (IJETT) – Volume 46 Number 5 April 2017

[7] Sensor-based system for verifying blood-pressure measurement position, Emma Smithayer, Dartmouth Computer Science Technical Report TR2012-720, May 2012

[8] Designing Heart Rate, Blood Pressure and Body Temperature Sensors for Mobile On-Call System, Dhwani parekh , Mc Master University,April 2010.

[9] Wavelet based pulse rate and Blood pressure estimation system from ECG and PPG signals, Computer, Communication and Electrical Technology (ICCCET), 2011 International Conference on, 18-19 March 2011, INSPEC Accession Number: 11973940, DOI: 10.1109/ICCCET.2011.5762486, Date Added to IEEE Xplore: 02 May 2011.

[10] A Tutorial of the Wavelet Transform Chun-Lin, Liu February 23, 2010.

[11] Discrete Wavelet Transforms - Theory and Applications Edited by Juuso Olkkonen Published by InTech Janeza Trdine 9, 51000 Rijeka, Croatia.

[12] Cuff-Free Blood Pressure Estimation Using Pulse Transit Time and Heart Rate, Ruiping Wang[1], Wenyan Jia[2], Zhi-Hong Mao[3,4], Robert J. Sclabassi[5], and Mingui Sun[2,3,4], Published in final edited form as: Int Conf Signal Process Proc. 2014 October ; 2014: 115–118. doi:10.1109/ICOSP.2014.7014980.

[13] Blood pressure estimation using neural networks, S.Colak,August 2004, DOI: 10.1109/CIMSA.2004.1397222

[14] Feature-Based Neural Network Approach for Oscillometric Blood Pressure Estimation, September 2011 IEEE, DOI: 10.1109/TIM.2011.2123210.

[15] BLOOD PRESSURE ESTIMATION USING NEURAL NETWORKS, S. Colak, C. Isik Electrical Engineering & Computer Science Department College of Engineering and Computer Science Syracuse University Syracuse, NY 13244.

[16] A Novel Neural Network Model for Blood Pressure Estimation Using Photoplethesmography without Electrocardiogram, Ludi Wang[1], Wei Zhou[2],Ying Xing[1], Automation School, Beijing University of Posts and Telecommunications, Beijing 100876, China and Functional Pharmacology, Department of Neuroscience, Uppsala University, Uppsala, Sweden, Received 10 August 2017; Revised 7 November 2017; Accepted 28 November 2017; Published 7 March 2018

[17] Pulse Transit Time and Blood Pressure During Cardiopulmonary Exercise Tests, T. WIBMER, K. DOERING1 , C. KROPF-SANCHEN , S. RÜDIGER , I. BLANTA , K. M. STOIBER, W. ROTTBAUER , C. SCHUMANN, Department of Internal Medicine, University Hospital of Ulm, Ulm, Germany Received May 29, 2013 Accepted November 29, 2013 On-line February 24, 2014, Physiol. Res. 63: 287-296, 2014.

[18] Introduction to Artificial Neural Network, A.D.Dongare, R.R.Kharde, Amit D.Kachare, International Journal of Engineering and Innovative Technology (IJEIT) Volume 2, Issue 1, July 2012, ISSN: 2277-3754, ISO 9001:2008 Certified.

[19] S. Savalia, V. Emamian, “Cardiac Arrhythmia Classification by Multi-LayerPerceptron and Convolution Neural Networks”, Published in MDPI Journal of Bioengineering, May 4, 2018.

[20] S. Savalia, E. Acosta, V. Emamian, "Classification of Cardiovascular Disease Using Feature Extraction and Artificial Neural Networks", Published in Journal of Biosciences and Medicines, ISSN Print: 2327-5081, Pages 64-79, Nov 2017.

[21] S. Alomari, M. Shujauddin, V. Emamian, "EKG Signals – De-noising and Features Extraction", Published in American Journal of Biomedical Engineering ISSN: 2163-1077, pp 180-201, 2016.

[22] Alharthi. V. Emamian, "Automated Mechanism for Early Screening and Diagnosis of Diabetic Retinopathy in Human Retinal Images.” published in British Journal of Applied Science & Technology, Volume 11 Issue 6, 2015.

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