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A Novel Regression based Technique to Estimate the Blood Pressure

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Abstract

In today's era due to sedentary and stressful lifestyle Health Monitoring has become one of the important areas to look upon. Wireless Body Area Network helps in improvement in the delivery and monitoring of health care. WBAN is a unique purpose sensor network that provides continuous health monitoring of a person through biosensors. One of the significant reasons that lead to increased number of deaths every year worldwide is cardiovascular illness. An abnormal high blood pressure or hypertension leads to cardiovascular illness. When the blood circulates in the body it applies a certain force on the blood vessels which is measured as Blood Pressure. It affects the cardiac output as well as blood vessels so it is an essential parameter that needs to be monitored. Commonly the device known as sphygmomanometer is used to measure blood pressure. But with the growth in IOT and wearable devices the demand of measuring Blood Pressure indirectly (without inflation, deflation of cuff) has increased. The Continuous monitoring of Blood Pressure method is an invasive one which is painful. To estimate the Blood Pressure indirectly and in a non invasive manner using other important signals such as ECG a method has been proposed which finds a correlation between the R peak that is the wave with maximum amplitude in an ECG Signal with the Arterial Blood Pressure. Regression analysis is performed on the dataset to estimate the blood pressure.

Keywords: *Wireless Body Area Network, Blood Pressure, ECG (Electrocardiograph), Regression Analysis.*

1. Introduction

A wireless body area network is a unique purpose sensor network that has a huge capability in the field of health monitoring. It can be used to monitor the patient's health during day as well as night using the biosensors which can be placed over the skin or implanted inside the body. The health report about the physiological variations of the patient can be wirelessly communicated to the doctor or the hospital so that continuous monitoring of the patient can be done.

One of the most commonly found disease among patients of almost all age groups is Blood Pressure, major cause being the sedentary and stressful lifestyle. The force with which the blood moves through the circulatory system is known as blood pressure. It is one of the most essential parameter which tells about the elasticity of blood vessels, cardiac output and physiological variations. There are various direct methods by which blood pressure can be measured such as sphygmomanometer, arterial tonometry, korotkoff method etc. The current methods used to measure the blood pressure in hospitals include the inflation and deflation of cuff, the continuous monitoring of blood pressure requires an invasive method which is very painful and leads to discomfort to the patient. The bedside patients often get irritated when the blood pressure is measured by the cuff based method which may lead to anxiety and stress to the patient. As the technology is progressing with increase use of sensors and Internet of Things, a method through which the blood pressure could be estimated indirectly is the need of hour.

Taking into account such reasons the wireless body area networks can serve to be a

fruitful method where in the sensors can be placed over the body. The emotions of a person can also be captured which can help to detect mood swings of a person. The various sensors that are prevalent in WBAN can record various parameters such as ECG (Electrocardiograph), EEG (Encephalogram), pulse rate etc. The various technical terms in relation to blood pressure are explained as follows.

1.1 Electrocardiogram(ECG)

An electrocardiogram is a measure of the electrical activity in the heart. The ECG is recorded by placing electrodes on the body. The P, Q, R, S and T waves in the ECG as shown in Fig 1 are due to rhythmic electrical depolarization and repolarization of the myocardium which is associated with the contraction of the atria and ventricles of the heart. Out of all waves QRS complex is the most significant one which defines the axis of the ECG. The duration, amplitude of the QRS Complex is useful in diagnosing cardiac disorders.

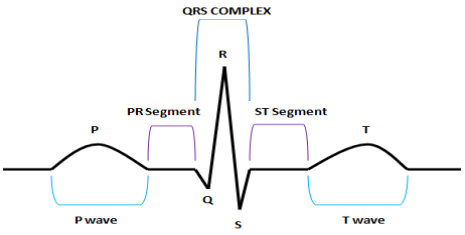

Fig. 1 Components of an ECG Wave

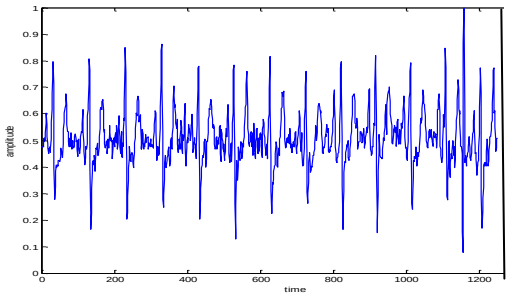

Fig .2 Raw ECG Signal

1.2 Photoplethysmogram (PPG)

The volumetric changes that take place in the blood during circulation is depicted by the PPG waveform. It uses low intensity infrared light which is absorbed by the blood and the changes in the intensity of lights depicts the changes in the flow of the blood. Most common device that measures the PPG is Pulse Oximeter. The raw PPG signal wave is depicted in fig 3.

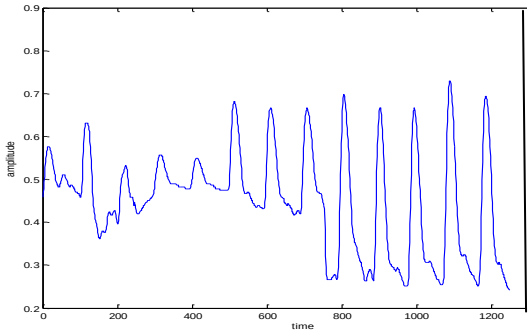

Fig. 3 Photoplethysmograph Signal (PPG)

1.3 Blood Pressure

It is generally measured as a combination of Systolic and Diastolic pressure where systolic blood pressure is the highest pressure when the heart contracts and the diastolic blood pressure is when the pressure is lowest during the period when the heart relaxes. The blood pressure of 120/80 mmHg is considered normal one. The blood pressure signal wave is depicted in Fig 4.

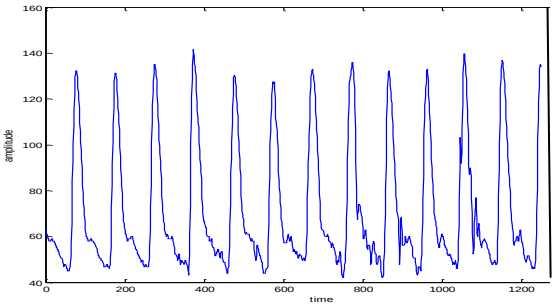

Fig .4 Blood Pressure Signal

The next section describes the various techniques that have been proposed by different authors for the estimation of Blood Pressure.

2. Literature Survey

Xiaoping P et.al [10] talks about a method in which the Arterial blood pressure, ECG

signals and PPG signals are taken. The delay between the R peak of ECG signal and the peak of the PPG signal is calculated to find the pulse transit time (PTT). The correlation values of SBP (Systolic Blood Pressure) , DBP (Diastolic Blood Pressure) and mean BP versus pulse transit time were calculated based upon the data points. The highest correlation value of PTT was with SBP & DBP.

Sahoo et.al [11] used Discrete wavelet transform (DWT) for the noise removal from the ECG and PPG signals which were taken from individual persons. The ECG and PPG signals are decomposed into 8 levels by discrete wavelet transform (DWT) using daubechies 6 wavelet [11]. The QRS complex is obtained. Similarly for PPG signal noise removal process is done. After the preprocessing of the signals the PTT is obtained using which the author finds the blood pressure which is inversely proportional to the PTT.

Xiaochuan He et.al [12] concentrates on a parameter of photoplethysmograph (PPG) i.e. dicrotic notch which is the relative amplitude of secondary peak. This parameter is used for the estimation of systolic BP (SBP). The method uses multiple regression with pulse arrival time, heart rate and Time_deri_b, where Time_deri_b is the duration from the maximum derivation point to the maximum of dicrotic notch in the PPG signal [12]. The dicrotic notch lies between the two peaks of the PPG signal. At times the dicrotic notch is difficult to find and Author has proposed three methods for finding the dicrotic notch 1) symmetrical curve fitting (SCF) method; 2) Gaussian curve fitting (GCF) method; and 3) adaptive curve fitting (ACF) method [12].The correlation value for SBP and PTT is calculated and then the multiple regression is applied.

Magavi et.al [13] has proposed a mathematical model for Estimation of Mean Arterial Pressure from ECG and BP. In this method the ECG and BP recordings are loaded from the source data. The removal of noise (low frequency components) from the ECG signals is done by using Golay filter. A threshold is provided in order to adjust the preprocessed signal and then P, QRS , T peaks of ECG signal are extracted using MATLAB equations , then the PTT is calculated as the time period between the ECG R-peaks and the troughs, peaks and zeros of the SBP and DBP, respectively. The outlier removal and smoothing method is applied on the PTT. The detected maximum of PTT signal is the estimated MAP.

Gendy et.al [15] proposed relationship of BP with pre-processed ECG signal. The peaks of R and T waves are indentified by applying the wavelet transforms.
From half of the maximum amplitude of the R wave until the maximum amplitude of the T wave is the systole part, and from half of the maximum amplitude of the T wave until half of the maximum amplitude of the following R wave is the diastole part in the ECG signal [15].
Two Neural networks are used to characterize the portions of systole and diastole extracted from the ECG signal. The training sample for the ANN consists of actual and calculated values of systole and diastole portion after training the classifier it was applied on the test signals. The results show and interrelationship between ECG and blood pressure.

3. Proposed Methodology

The proposed methodology is depicted through the flowchart shown in fig.5.The work finds correlation between the R peak (the wave in ECG signal with maximum amplitude) and the Arterial Blood Pressure. To estimate the blood pressure the regression analysis is used.

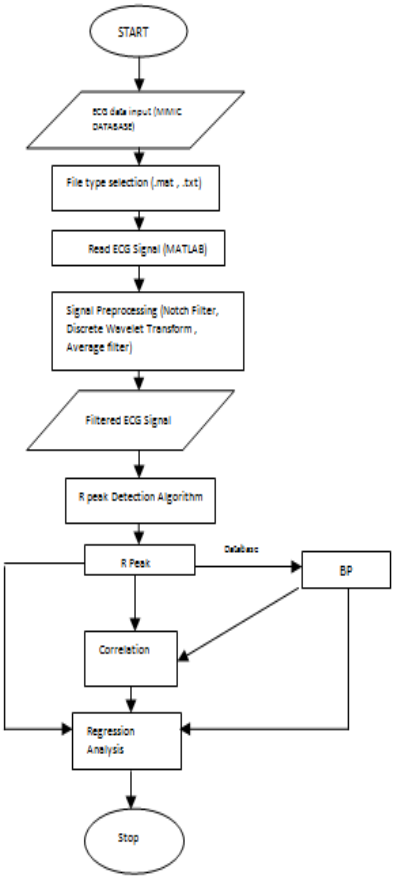

Fig. 5 Flowchart

3.1 Mimic Database

Multiparameter Intelligent Monitoring in Intensive Care database contains multiple recordings of physiologic signals of bedside patients like blood pressure ,ECG, pulse etc with time series.

3.2 Signal Acquistion

The Electrocardiograph and Blood Pressure signals are taken from the MIMIC (Multiparameter Intelligent Monitoring in Intensive Care) Database as .mat file using PhysioBank ATM. For the ECG signal the lead II is taken for experiment purpose. The signals thus extracted are loaded into MATLAB and the plotted signals are shown in Fig.5.

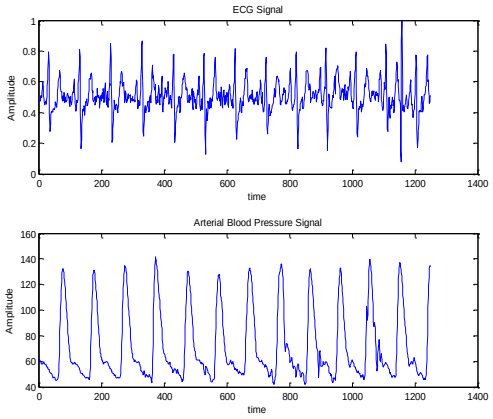

Fig. 5 ECG Signal & Arterial Blood Pressure Plot

3.3 Signal Preprocessing

When the ECG signals are recorded they are affected by noise and artifacts that are present in the same frequency band as that of the ECG signal. Hence to find the useful information from these signals there is a need to preprocess the ECG Signal. The preprocessing of the signals requires relevant filters and thresholding.
The Raw ECG signal is depicted in Fig.6.

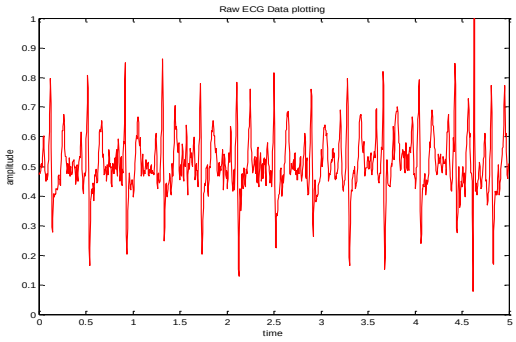

Fig. 6 Raw ECG Signal

The relevant filters used in the signal preprocessing are

- Firstly a Notch filter (band stop filter) is applied to the ECG Signal where most of the frequencies pass unaltered but some frequencies that lie in a specific range are attenuated to very low levels.

• After that the ECG signal is decomposed into 8 levels by discrete wavelet transform (DWT) using daubechies 6 wavelet. The tenth level is subtracted from the original signal and the denoised and baseline corrected signal is obtained.

• Finally the Average filter is used to remove the glitches to increase the performance of peak detection. The filtered signal is depicted in fig 7.

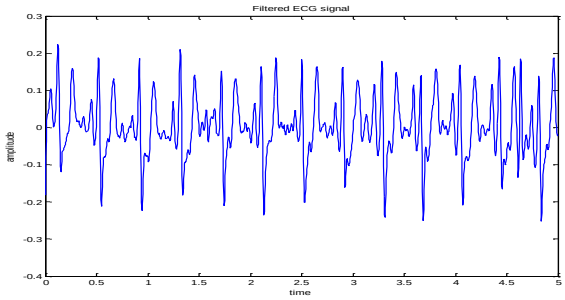

Fig. 7 Filtered ECG Signal

3.4 R Peak Detection

After acquiring the filtered signal the R peak (the wave with maximum amplitude) is detected in MATLAB using the R peak detection algorithm. The threshold signal will be different for different ECG signal.

R Peak Detection Algorithm
Input : fil_ecg: filtered ECG Signal
th: threshold value
Output : R peak position and value
Procedure :
Start
{
//variable initialisation
i ← 2
th←0.45*max(fil_ecg)
time←0
j←[ ]
N1←length(fil_ecg)
Repeat steps until i<=N1-1
{
if fil_ecg(i) > fil_ecg(i+1) and if fil_ecg(i) > fil_ecg(i+1) and if fil_ecg(i) > th

then store the point as R peak // position and value is stored
}
}

The red marks are the peak points detected in the ECG signal.

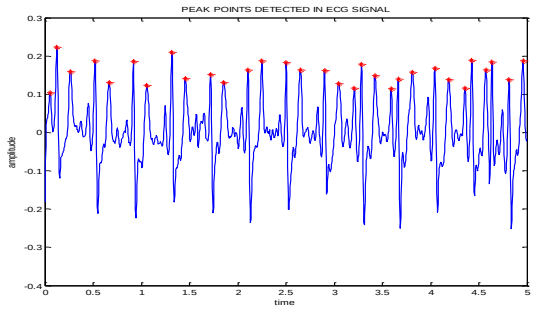

Fig.8 Detected R peaks of the ECG Signal

3.5 Correlation

Correlation value indicates the strength and direction of the relationship between the two variables. The correlation values between the ECG R peak and the arterial blood pressure is calculated using the *Karl Pearson Correlation* of Coefficient. The formula is as follows :-

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2]}\sqrt{[n\sum y^2 - (\sum y)^2]}}$$

x is R peak value
y is arterial blood pressure value
n = no. of observation taken into consideration

Karl Pearson Correlation is used because it

- Tells about whether there is a relationship between the two variables or not and the amount or degree of correlation.
- Can help in finding the value of the dependent variable using regression analysis.

3.6 Regression Analysis

Regression analysis is a powerful statistical method that examines the relationship between two or more variables of interest. The work uses regression analysis to find the regression curves and estimate the blood pressure.

4. Results

The experiment was conducted on a single patient data and approximately 4000 recordings of that patient is considered for numerical evaluation. The correlation value of 0.4499 depicts that there is a low degree of positive correlation between the two variables that are ECG R peak and Arterial Blood Pressure. Fig. 9 depicts the linear, quadratic and cubic curves (ECG R peak value vs. Arterial Blood Pressure). The norm of residuals shown in Fig.10 depicts that the cubic curve fits the data more accurately its norm of residuals is minimum among all the curves.

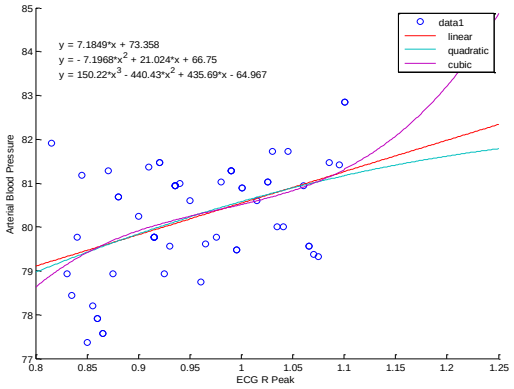

Fig.9 Regression Curves

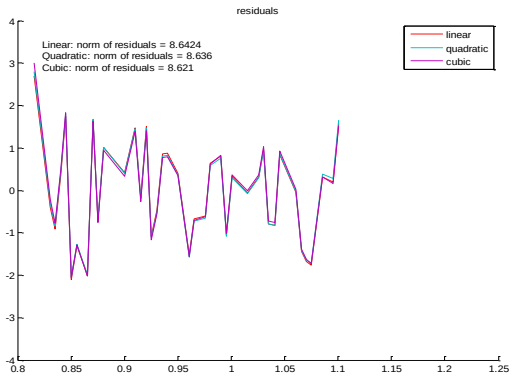

Fig.10 Norm of Residuals

Certain values of R peak are put into the regression curves and the estimated results (y= f(x)) are plotted as shown in fig.11.

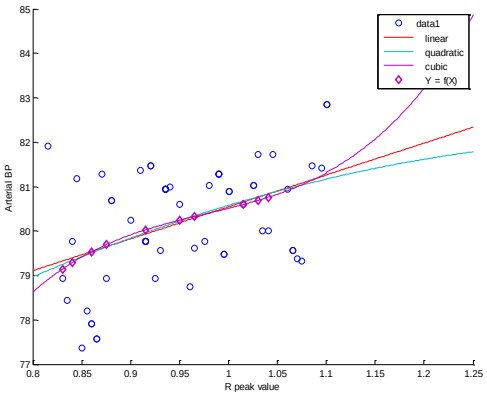

Fig.11 Estimated Blood Pressure Values

Table 1 Error Calculation

S.No.	Actual BP ('mmHg')	Estimated BP ('mmHg')	Error Value (Actual BP- Estimated BP)
1.	80.0066	80.8	-0.7934
2.	78.9321	79.6	-0.6679
3.	77.6155	80.3	-2.6845
4.	80.5728	80.2	0.3728
5.	77.9063	79.5	-1.5937
6.	80.5928	80.7	-0.1072
7.	78.9321	79.3	-0.3679
8.	81.7162	80.8	0.9162
9.	79.224	79.1	0.124
10.	79.7624	79.1	0.6624

Table I above depicts the calculation of the error which is calculated as:-

Error= Actual BP – Estimated BP

The Table only consists of 10 data points but the experiment was calculated on many data points, the maximum error that was recorded is ±8mmHg.

5. Conclusion & Future Work

The work proves that there is low degree of positive correlation between the ECG R peak and Blood Pressure therefore we could estimate the blood pressure using the Regression Analysis. The experiments were done on a single patient database in future the idea is to take into consideration minimum 10 patients. The work will also incorporate data acquisition through sensor modules such as AD 8232 module which can capture a person's ECG to make a real time processing system. The author aims to improve the accuracy of the system.

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