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Non Linear Regression Analysis to Estimate Blood Pressure

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Abstract **One of the significant reasons that cause large number of deaths worldwide is cardiovascular illness. An abnormal high blood pressure leads to cardiovascular illness. Blood pressure is the force through which the blood circulates in the circulatory system. Thus monitoring of blood pressure is a necessary task. Wireless Body Area Network helps in monitoring of a patient's physiological parameters continuously. The device known as sphygmomanometer is commonly used to measure blood pressure. The continuous measurement of blood pressure is very painful as it requires needle insertion inside the artery. But with the growth in IOT and wearable devices the demand of measuring Blood Pressure indirectly (without inflation, deflation of cuff) is increasing day by day. To estimate the Blood Pressure in a non invasive manner a method based on Non Linear Regression has been proposed.**

Keywords — **Blood Pressure (BP), Electrocardiograph (ECG), Regression, Signal Preprocessing, Wireless Body Area Network (WBAN), Wireless Sensor Network (WSN)**

I. INTRODUCTION

Wireless Sensor Networks is in great demand as the technology of sensors is being upgraded day by day. Now a days, smart watches which can monitor certain physiological parameters of a person such as heart rate , number of steps that person has walked etc. are very popular. The stressful and sedentary lifestyle leads to various types of diseases, High or Low blood pressure being the prominent among them [9]. Wireless Body Area network which is a subset of wireless sensor network can play a big role in monitoring the health of a person.

There are few conventional methods to monitor blood pressure out of which the use of sphygmomanometer is the mostly used in hospitals [10]. This method requires inflation and deflation of cuff which can lead to uneasiness to the bed side patients especially because they are continuously undergo various types of tests. WBAN's improvises a patient's lifestyle by guiding the patient through internet by investigating its vital parameters recorded through sensors. This could prevent the revisit to the doctor again and again.

A. Wireless Body Area Network (WBAN)

WBAN is a special purpose sensor network that consists of nano/bio sensors which can be placed over the body, inserted under the skin or can be wearable. These sensors can monitor the person's various physiological parameters such as ECG, EEG etc. The basic terminologies in Wireless sensor network are explained below.

B. Blood Pressure

The blood moves through the circulatory system with the help of a force called blood pressure. It is measured between the systolic and diastolic pressures. When the heart contracts, the blood pressure becomes highest and is referred to as Systolic Blood Pressure and when the heart relaxes the pressure becomes the lowest, is referred to as Diastolic Blood Pressure.

C. Electrocardiogram (ECG)

The electrical activity caused by contraction and relaxation of atria and ventricles in the heart is recorded as Electrocardiogram. The components of an ECG wave are P, Q, R, S and T waves as shown in Fig 1. The main line seen in an ECG is the QRS complex. The wave with the maximum amplitude which can be easily seen is the R wave.

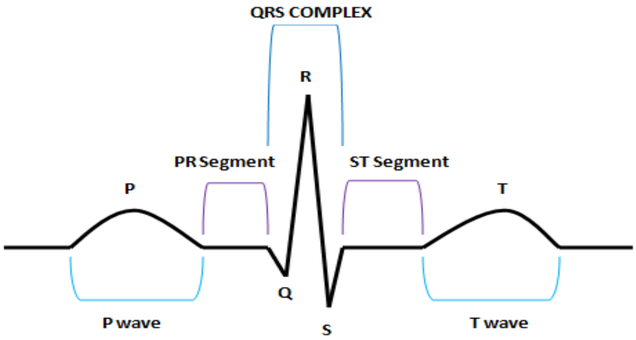

Fig. 1 Components of an ECG Wave

II. LITERATURE SURVEY

Extensive literature survey that was carried out threw light on the various upcoming technologies in wireless

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sensor network of which the wireless body area network is one such technology. Wireless body area network is a blessing that can be used to monitor the health of a person. Out of all the signals the blood pressure signal is a very important signal which needs to be monitored.

The blood pressure measurement can be done using some of the conventional and direct techniques such as Oscillometric method , Korotkoff method, Mercury Sphygmomanometers , Arterial Tonometry and Volume-Clamp method[1][2][3].

Kleinman C.S. and Seri I. [1] has talked about the Oscillometric method which was proposed in the year 1876. In the method the oscillations in a BP monitor cuff are recorded during deflation. The recordings are the required BP measurement but it had few disadvantages such as it was not precise in case of arrhythmia patients and cost of device was high.

Simmers .L. [2] has written about the most commonly method that is used for BP measurement which is Mercury Sphygmomanometers. It was developed in the year 1896. The glass tube is dipped in a bowl of liquid mercury and graded in mm Hg.

Heyward H.V. and Gibson .A [3] has talked about the Automated Arm Sphygmomanometers which is a direct technique developed in year 1897.This is digital BP measurement method. The digital monitoring component is connected to an inflatable cuff worn around an electronic display. The electronic display shows the measured BP but is not accurate with patients with irregular heartbeats or arterial stiffness.

As the existing techniques are cuff based and the continuous blood pressure measurement is quite painful so some of the authors have proposed indirect techniques for the blood pressure monitoring few of them have been described in the literature survey.

Magavi et. al. [4] proposed a model in which the ECG and Blood pressure (SBP, DBP) recordings are taken from some source data. For the removal of noise from the ECG signals golay filter was used and the low frequency components were removed. In the ECG signal P, QRS , T peaks are extracted using MATLAB , after that the pulse transit time is calculated as the time period between the ECG R-peaks and the troughs, peaks and zeros of the SBP and DBP, respectively The detected maximum of PTT signal is the estimated Mean Arterial pressure. Hence the Mean Arterial Pressure is estimated using ECG and BP signals.

Sahoo et.al. [5] talked about a method in which the signals were acquired from biokit at the rate of 1000 samples/second. The noise removal was performed using the discrete wavelet transform. The signals were decomposed into 8 levels by daubechies 6 (db6) wavelet. After acquiring the noise free signals, QRS Complex were obtained The type of relationship between the variables was known using correlation analysis and lastly an inversely proportional relationship between pulse transit time and blood pressure was found.

Estrada et.al. [6] proposed a methodology in which relationship between the Blood Pressure and ECG signal was deduced. The wavelet transform was applied to know the peaks of R and T waves. Further neural networks were used for distinguishing the systole and the diastole parts taken from the ECG signal. The artificial neural were trained for the training sample and after that the classifier was applied on the test signals. The results showed that there exists a relationship between ECG and blood pressure.

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.

III. PROPOSED WORK

The monitoring of blood pressure monitoring has become important in health care monitoring as it is the second largest leading cause of deaths worldwide. The extensive literature survey reveals that the cardiovascular illness is also caused due to the high or low blood pressure. It also summarizes the various types of monitoring methods. These can be broadly classified into direct and indirect techniques. The focus was on the indirect techniques proposed by various authors. They majorly took two signals that are ECG signal and photoplethysmograph (PPG) signal for blood pressure estimation. Though there were certain problems associated with those techniques such as they are time consuming, signal preprocessing becomes complex. They require calculation of a third parameter that is pulse transit time which is a tiring task.

The proposed work is the extension of the already done work of the author where linear regression was used. This work aims to use quadratic regression for estimating the blood pressure using ECG signal. The signals are extracted from the MIMIC Database [7]. The flowchart of the proposed work is shown in fig.2.

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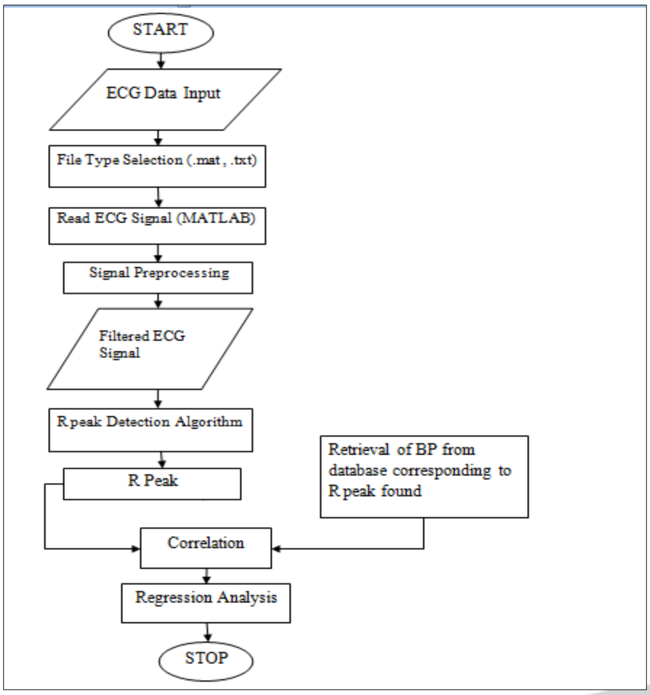

Fig. 2 Flowchart

The steps involved in the proposed work are as follows:-

- Import the extracted .mat files in MATLAB.
- Signal Preprocessing - Notch Filter is applied for the removal of noise in the ECG signal.
- The filtered ECG signal is fed into the R peak detection algorithm.
- The blood pressure values are extracted from the datasheet corresponding to the R peak detected.
- Correlation Analysis is used to find the kind of relationship that exists between ECG signal and blood pressure signal.
- Finally the work uses the Quadratic Regression for estimating the blood pressure.

The signal thus imported in MATLAB is depicted in fig 3.

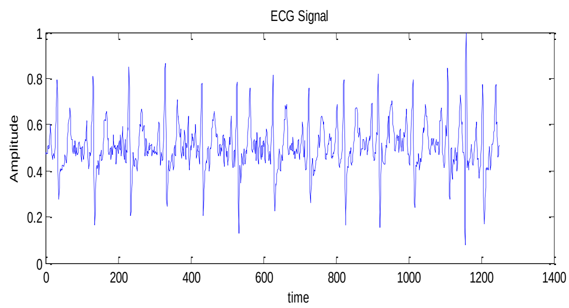

Fig.3 ECG Signal

Signal is preprocessed using the following filters.

A. Notch Filter

The notch filter with a narrow bandwidth is also called as the band stop filter. Notch Filters have some advantage over low pass filters they only remove a narrow band of frequencies whereas low pass filters attenuate all signals above a specific frequency. The notch filters pass the components of the frequency that are above and below the notch frequency. The notch filters strongest attribute is that they can pass the high frequencies and they cause a very little phase lag at the crossover frequency.

B. Mean filter

The mean filter is a simple sliding-window spatial filter. In mean filter the average (mean) of all the pixel values in the window replaces the center value in the window. The shape of window can be of any shape but it is usually square. The mean filter is illustrated using an example given below.

Unfiltered values

4 102

8 5 6

3 9 7

4 + 10 + 2 + 8 + 5 + 6 + 3 + 9 + 7 = 45

54/ 9 = 6

Mean filtered

* * *

* 6 *

* * *

The mean of all the values that is 6 replaces the centre value which was previously 5.

The fig. 4 depicts the raw ECG signal whereas in fig.5 shows the filtered ECG signal i.e. obtained after signal preprocessing.

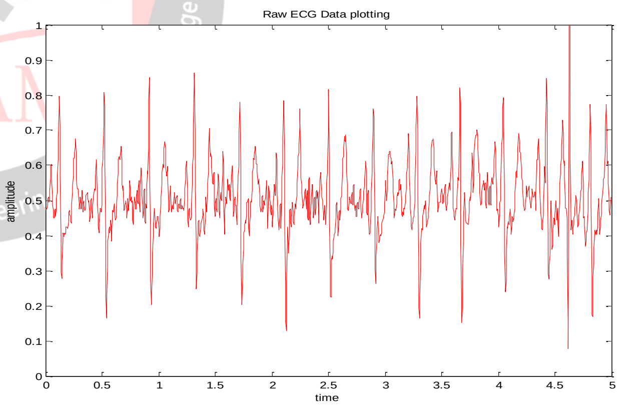

Fig. 4 Raw ECG Signal

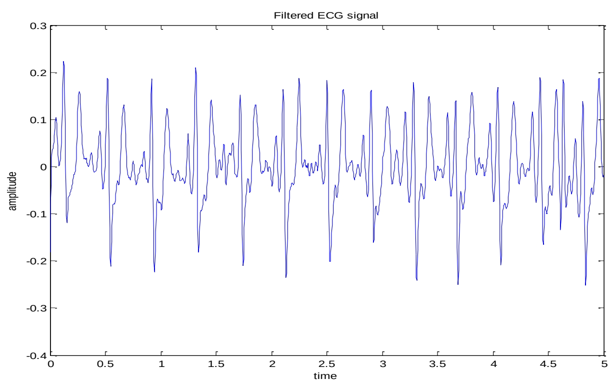

Fig. 5 Filtered ECG Signal

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After the filtered signal is received the R peak of the ECG Signal is detected using peak finder with proper threshold value in MATLAB. The detected R peaks are shown in fig.6.

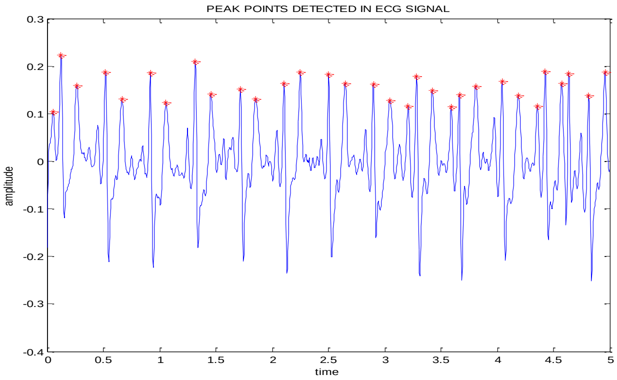

Fig.6 R peak detected in an ECG Signal

Retrieval of blood pressure values from the dataset obtained from MIMIC database corresponding to the R peak value detected is shown in the table below.

Table I Blood Pressure Values

Blood Pressure Values	
78.19941	79.56705
79.46936	81.27659
81.71619	80.93468
80.93468	78.93207
80.25086	79.46936
77.56444	79.56705
80.00664	78.73670
81.03237	78.93207
79.76242	77.36906
81.17890	79.32283

C. *Non Linear Regression*

Regression analysis is a powerful statistical method that examines the relationship between two variables. For estimating the blood pressure the quadratic regression is applied.

Let the quadratic regression y on x is

$$y = p1x^2 + p2x + p3 \qquad (1)$$

Where y is blood pressure and x is the ECG R peak.

p1 , p2 ,p3 are coefficients of the quadratic curve whose values are to be determined by using the normal equations.

Normal Equations are :-

$$\sum y = p1\sum x^2 + p2\sum x + Np3 \qquad (2)$$

$$\sum xy = p1\sum x^3 + p2\sum x^2 + p3\sum x \quad (3)$$

$$\sum x^2y = p1\sum x^4 + p2\sum x^3 + p3\sum x^2 \ (4)$$

Solving (2), (3) and (4) we get values of p1 , p2 and p3.

Putting the values of p1, p2 and p3 in (1) we get $y_c = p1x^2 + p2x + p3$ (5).

IV. RESULTS

The graph in Fig. 7 depicts the quadratic curve obtained using the regression analysis performed on the dataset. The X axis represents the R peak value and the Y axis depicts the arterial blood pressure value.

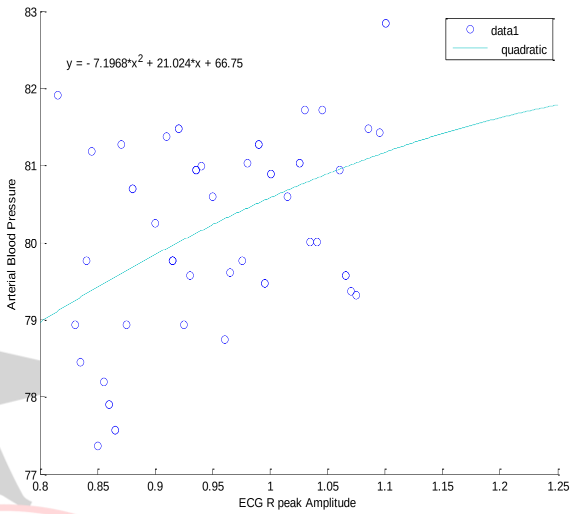

Fig. 7 Quadratic Curve

Coefficients along with confidence bounds are:-

p1 = -7.197 (-57.95, 43.55)

p2 = 21.02 (-76.64, 118.7)

p3 = 66.75 (20.01, 113.5)

Norm of Residuals: This parameter describes how good the fit is and a smaller value of norm residuals indicates a better fit than a fit with larger norm of residual value. It is calculated using the norm function, norm(V,2) , where V is the vector of residuals. It is shown in fig.8.

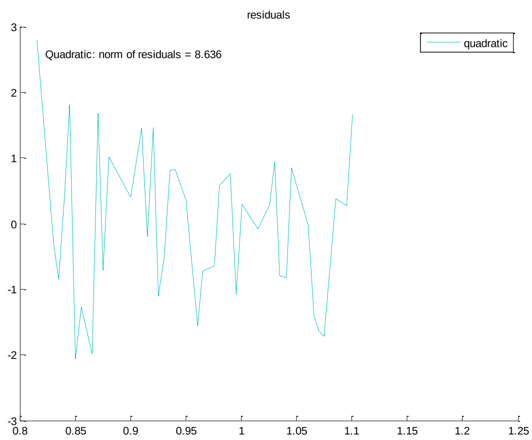

Fig. 8 Norm of Residuals

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V. ANALYSIS

Testing Data is applied to the Regression curves. The data set was taken from MIMIC database itself and the ECG signal's R peak was detected and then the value of the Peak was put into the curve obtained in the basic fitting toolbox.

The estimated values of the blood pressure are shown below:-

Table III Estimated BP values & Error Estimation

ACTUAL ABP ('mmHg')	ESTIMATED ABP ('mmHg')	ERROR VALUE = ACTUAL ABP – ESTIMATED ABP
79.23	78.9	0.33
80.12	79.8	0.32
80.63	79.8	0.83
78.73	80.3	-1.57
80.59	80.5	0.09
82.10	80.7	1.4
81.03	80.8	0.23
79.35	81.0	-1.65
81.42	81.1	0.32
81.45	81.2	0.25

A. *Error Estimation*

The total percentage error is used to depict the difference between the estimated value and actual value.

The total percentage of error is calculated using the formula given below:-

$$\%\,err = \frac{\sum |actual - estimated|}{\sum actual} \times 100$$

actual – actual blood pressure values

estimated- estimated blood pressure values obtained using (5)

% Error calculated = 1.02

VI. CONCLUSION

The work shows that there exists a relationship between the ECG Signals R peak and the arterial blood pressure. Quadratic Regression analysis is applied in MATLAB to estimate the blood pressure using the amplitude of R peak. The estimated blood pressure values are shown in table III. The total percentage of error (+1.022) depicts that the estimated value of blood pressure value is nearer to the actual blood pressure value. This error is less than the error that was obtained when linear regression was used to estimate the blood pressure (+1.069). In future the author also aims to acquire the ECG signals using the AD 8232 Module and make a real time processing system.

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