Machine Learning Approach for Blood Pressure Measurement Using Bio-Impedance

Kanthalakshmi.S[1], Bhavishyashri.C.S[2]
{skl.eee@psgtech.ac.in[1], 21MR01@psgtech.ac.in[2]}

Department of EEE, PSG College of Technology[1 2]

Abstract. Continuous monitoring of flow of blood in the blood vessel is of paramount importance in heart related healthcare, particularly in the management of hypertension. Impedance plethysmography (IPG) is a non-invasive diagnostic method used for signal measurement and assessing the condition of a patient's arteries, specifically the carotid artery. In order to achieve accurate IPG-based carotid pulse detection for heart related diagnostic applications, this paper presents a set of optimized measurement parameters to effectively capture the pulsations originating from the carotid artery. The analysis in this study explores the influence of factors such as the excitation current frequency, the electrode crosssectional area, electrode arrangements, and the physiological location of the carotid arteries on the resolution of IPG measurements. This research contributes to the efficient measurement of bioimpedance, facilitating the accurate determination of Blood Pressure (BP) values. In this study, electrodes are placed over carotid artery to measure bio-impedance. The obtained impedance value is collected as database and a model is created using XGBoost regression algorithm. This model is trained and tested for accuracy measures by estimating RMSE and ME values with standard criteria.

Keywords: Bio-impedance, XG Boost Algorithm, impedance plethysmography

1 Introduction

The analysis done by World Health Organization (WHO), claiming approximately 18 million lives each year, heart diseases stand as a leading cause of death,. Chronic heart diseases, including conditions like hypertension and arrhythmia, necessitate continuous monitoring for the assessment of heart health over the long term. In clinical practice, the use of intra-arterial catheters is a common method for monitoring critical blood flow parameters like blood pressure and pulse rate. However, this approach is invasive and carries the risk of adverse complications for the patient. Recent advancements in medical research have yielded various wearable devices and technologies designed to enable unobtrusive, extended monitoring, thus eliminating discomfort and enhancing long-term

ICSETPSD 2023, November 17-18, Coimbatore, India

DOI 10.4108/eai.17-11-2023.2342840

cardiovascular observation. These wearable biomedical sensors have been introduced to address the challenges associated with arterial catheters, offering real-time monitoring of hemodynamic parameters, including pressure pulse waves and continuous BP measurements [1] [2]. One of the proposed methods is based on photo plethysmography (PPG) [3], which is an optical technique using properties of light to detect changes in blood volume. PPG has been widely used non-invasive, wearable devices for recording heart rate and blood pressure [4]. However, PPG is limited to superficial arteries like the radial artery due to its limited ability to penetrate deeper tissues. Other continuous hemodynamic monitoring methods make use of capacitive pressure sensors and piezoelectric sensors. Arterial pulsations is detected by Capacitive pressure sensors through changes in the distance between two parallel plates and their electrical capacitance. Due to small variations in distance between the electrodes, capacitive pressure sensors have low sensitivity. Piezoelectric sensors extract pressure pulse waves from the radial artery and calculate beat-to-beat blood pressure measurements. The major limitation is the requirement of consistent pressure between the skin and the sensor to maintain coupling conditions during measurements. The primary limitation of pressure sensors is the discomfort caused by semiocclusive measurements, making them unsuitable for long-term monitoring. Despite significant advancements in wearable cardiovascular systems, the need for multiple channels for physiological measurements poses challenges. For instance, Pulse Transit Time based blood pressure monitoring relies on two-channel physiological signal acquisition, combining ECG and PPG devices or using two PPG sensors to obtain two-channel PPG signal measurements from subjects for calculating pulse transit time and estimating blood pressure. However, this reliance on multiple devices can lead to complexity and inconvenience in wearable applications [5][6][7]. The Impedance Plethysmography (IPG) technique leverages electrical impedance principles to represent the continuous bio-impedance waveform when subjected to a small alternating current. In contrast to PPG and pressure sensors, IPG overcomes the challenges associated with the limited light penetration of PPG sensors and the semi-occlusive nature of pressure sensor measurements. This is achieved through the electrical impedance measurement mechanism. Several studies have explored the application of the IPG-based technique for continuous blood pressure monitoring and monitoring deep veins in the leg.

2 IPG-based carotid artery pulse sensing

The IPG measurement method relies on the electrical impedance principle, employing two pairs of electrodes positioned on specific body segments. A small AC current is injected into human body using the excitation electrodes and the sensing electrodes will capture the change in arterial impedance under continuous AC stimulation. When it comes to sensing arterial pulsations, the IPG technique effectively captures change in real-time arterial impedance caused by fluctuations in blood volume within the artery during both diastole and systole phases, as depicted in Figure 1.

Arterial impedance can be divided into two components: basal impedance (Z_{basal}) and pulsationinduced impedance ($Z_{pulsation}$). Z_{basal} and $Z_{pulsation}$ are given through Equations (1) and (2) applying Ohm‘s law, assuming consistent blood resistivity, uniform arterial pulsations caused by blood volume changes, and parallel alignment of driving currents with the carotid artery.

In Equations (1) and (2), the variables ρ represent blood resistivity, L represent the measured

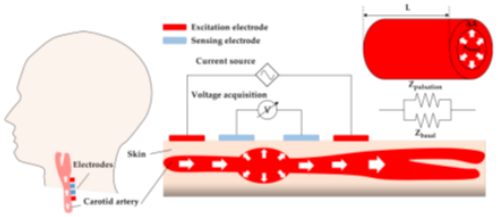

Fig. 1. Schematic of IPG-Based Carotid Pulse Sensing and Equivalent Electrical Model

length of the arterial segment, Abasal, Δ A denote unchanging basal cross-sectional area, and the change in arterial cross-sectional area of the artery, respectively:

$$Z_{basal} = \rho \left(\frac{L}{A_{basal}} \right) \tag{1}$$

$$Z_{pulsation} = \rho \left(\frac{L}{\Delta A} \right) \tag{2}$$

The electrical model equivalence can be visualized with Z_{basal} and $Z_{pulsation}$ in parallel, as expressed in Equation (3):

$$Z(t) = \left(\frac{1}{Z_{basal}} + \frac{1}{Z_{pulsation}} \right)^{-1} \tag{3}$$

The impedance change of the carotid artery due to volume changes can be calculated using Equation (4):

$$\Delta Z = \left(Z_{basal} \,||\, Z_{pulsation} \right) - Z_{basal} = -\frac{Z_{basal}^2}{Z_{basal} + Z_{pulsation}} \tag{4}$$

As the cross-sectional area of A_{basal} is much larger compared to AA under the assumption of constant blood resistance and the uniform measured length of the arterial segment, it can be assumed that Z_{basal} is much smaller than $Z_{pulsation}$ Equation (4) becomes:

$$Z_{pulsation} = -\frac{Z_{basal}^2}{\Delta Z} \tag{5}$$

Consequently, the arterial impedance variation induced by change in blood volume can be expressed using Equation (6):

$$\Delta Z = -\frac{Z_{basal}^2}{\rho L} \Delta A \tag{6}$$

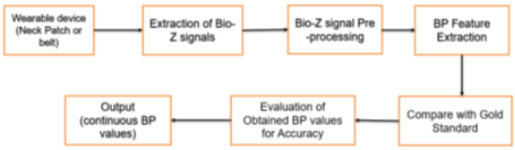

Fig. 2. Block Diagram of Proposed System

2.1 Block diagram

The block diagram of proposed system is shown in Fig.2.

The data are collected using MAX30001 development board which helps in measuring the bioimpedance from human body by providing physical interfaces for connecting the electrodes that are placed on carotid artery. The Maxim MAX30001 serves as an analog front-end for biopotential and bioimpedance measurements. Its primary purpose is to acquire data related to electrocardiograms (ECG), heart rate, pace detection, and respiration data through bioimpedance measurements. In this project, six subjects are measured at different times by placing the electrodes on carotid artery and the collected data (Bio-Impedance) measured is around 4000 for each subject. The time duration for data collection was 30s for each trial.

Measurements collected from the MAX30001 are converted to their impedance using the following relation:

$$Z(\Omega) = ADC \times \frac{V_{REF}}{2^{19} \times CC\_MAG \times GAIN} \tag{7}$$

In this equation, Z represents the recorded magnitude, ADC_{out} represents for the equivalent digital reading of the analog detected voltage, V_r denotes the reference voltage, CM signifies the current excitation magnitude as decided by the user, and G denotes internal amplification applied to the voltage measurement as selected by the user.

3 Results

The bio-impedance captured from MAX30001 for different subjects to measure accurate bioimpedance from body are configured in the MAX30001 interface by considering the following parameters,

- Frequency range: 1Khz to 128Khz
- Current range:8μA to 96μA
- Sampling rate: 64sps
- Gain:20V/V
- Impedance measured at 50Khz

- Current excitation is 8μA

The bio-impedance captures for subject 1 is shown in Fig.3 for time period of 13s.

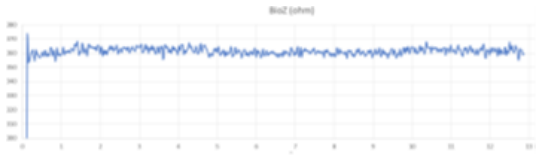

Fig. 3. Bio-Impedance Measurement for subject 1

After capturing the bio-impedance for six subjects all these data are collected in the excel form in order to train and test the model to extract blood pressure values and compare them with the gold standard to check the accuracy and infer the difference for designed model with the reference. Once the SBP and DBP model are created, after training and testing of models created, the accuracy measures are calculated providing the RMSE (Root Mean Square Error) and ME (Mean Error) for both the models and tabulated as shown in the Table 1 and 2 for DBP and SBP model respectively. [7]

S.NO	Feature Name	Subject ID	training DBP	ME	RMSE	Testing DBP	ME	RMSE
0	Bio-Z	1	2204	-0.00057	0.075277	94	6.137622	7.699867
1	Bio-Z	2	3620	0.000816	0.076948	43	21.94075	22.30104
2	Bio-Z	3	2667	0.001373	0.064299	277	-0.87758	5.689114
3	Bio-Z	4	3440	-0.00088	0.085752	347	6.184595	8.917418
4	Bio-Z	5	2982	0.000253	0.078799	442	20.61529	23.35123
5	Bio-Z	6	4348	-0.00123	0.070981	235	-11.2052	14.4606

Fig. 4. ME and RMSE Calculation for DBP Model Created

S.NO	Feature Name	Subject ID	Training SBP	ME	RMSE	Testing SBP	ME	RMSE
0	Bio-Z	1	2204	0.003456627	0.103272284	94	8.915414	10.55107
1	Bio-Z	2	3620	0.002215598	0.108576535	43	8.754492	10.48120
2	Bio-Z	3	2667	0.001009537	0.130871466	277	14.00759	18.43882
3	Bio-Z	4	3440	0.001403845	0.094247477	347	10.52235	12.19685
4	Bio-Z	5	2982	0.002054448	0.088899909	442	2.169496	8.842573
5	Bio-Z	6	4348	6.34E-05	0.138954897	235	6.903985	14.539

Fig. 5. ME and RMSE Calculation for SBP Model Created

3.1 Statistical results

The reference and estimated values of Systolic blood pressure and Diastolic blood pressure models are compared and plotted using scatter plot, the linear regression analysis is done to line fitting the developed model. The plot is shown in Fig.4 and 5 for Systolic blood pressure and Diastolic blood pressure models.

Fig. 6. Scatter Plot of Reference and Predicted Data – DBP Model

Fig. 7. Scatter Plot of Reference and Predicted Data – SBP Model

4 Conclusion

The measurement of bio-impedance using MAX30001 was captured and the data sets were collected for different subject with multiple trials on different days in order to figure out whether there are vast changes in measurement of bio-impedance at different times or not. The bioimpedance of body changes in huge difference only when the patient suffers from any illness or serious health conditions which can be reflected while measuring. Here, the subjects were in good health condition and while taking measurement the subjects were calm in sitting position. The statistical results shows that the accuracy can be further more improved and multiple subjects with different health conditions and many other features can be added in order to see the difference while measuring bio-impedance in future work.

References

[1] Khan Y, Han D, Ting J, Ahmed M, Nagisetty R, Arias AC. Organic Multi-Channel Optoelectronic Sensors for Wearable Health Monitoring. IEEE Access. 2019;7:128114–128124. Avail-

able from: http://dx.doi.org/10.1109/access.2019.2939798.

[2] Lochner CM, Khan Y, Pierre A, Arias AC. All-organic optoelectronic sensor for pulse oximetry. Nature Communications. 2014 Dec;5(1). Available from: http://dx.doi.org/10.1038/ncomms6745.

[3] Poh MZ, Poh YC. Validation of a Standalone Smartphone Application for Measuring Heart Rate Using Imaging Photoplethysmography. Telemedicine and e-Health. 2017 Aug;23(8):678–683. Available from: http://dx.doi.org/10.1089/tmj.2016.0230.

[4] Wang TW, Chu HW, Chen WX, Shih YT, Hsu PC, Cheng HM, et al. Single-Channel Impedance Plethysmography Neck Patch Device for Unobtrusive Wearable Cardiovascular Monitoring. IEEE Access. 2020;8:184909–184919. Available from: http://dx.doi.org/10.1109/access.2020.3029604.

[5] Tabei F, Gresham JM, Askarian B, Jung K, Chong JW. Cuff-Less Blood Pressure Monitoring System Using Smartphones. IEEE Access. 2020;8:11534–11545. Available from: http://dx.doi.org/10.1109/access.2020.2965082.

[6] Ibrahim B, Jafari R. Cuffless Blood Pressure Monitoring from an Array of Wrist Bio-Impedance Sensors Using Subject-Specific Regression Models: Proof of Concept. IEEE Transactions on Biomedical Circuits and Systems. 2019 Dec;13(6):1723–1735. Available from: http://dx.doi.org/10.1109/tbcas.2019.2946661.

[7] Wang TW, Chen WX, Chu HW, Lin SF. Single-Channel Bioimpedance Measurement for Wearable Continuous Blood Pressure Monitoring. IEEE Transactions on Instrumentation and Measurement. 2021;70:1–9. Available from: http://dx.doi.org/10.1109/tim.2020.3035578.