International Journal of Scientific Research in Computer Science and Engineering
Vol.5, Issue.4, pp.36-40, August (2017)
Research Paper
E-ISSN: 2320-7639

LabVIEW based detection of Pulse Transit Time from Plethysmogram and ECG signals for estimation of Blood Pressure

[1*]Alister Dsouza, [2]M. S. Panse

[1]Dept. Electrical Engineering, VJTI, Mumbai, India
[2]Dept. Electrical Engineering, VJTI, Mumbai, India

Available online at: www.isroset.org

Received 10th Jun 2017, Revised 16th Jul 2017, Accepted 12th Aug 2017, Online 30th Aug 2017

Abstract—Blood Pressure is the pressure exerted by blood on the walls of arteries. Normal blood pressure is considered to be a systolic blood pressure of 120 millimetres of mercury and diastolic pressure of 80 millimetres of mercury (stated as "120 over 80"). If an individual were to have a consistent blood pressure reading of 140 over 90, he would be evaluated for having high blood pressure. If left untreated, high blood pressure can damage important organs, such as the brain and kidneys, as well as lead to a stroke. Thus it becomes important to measure blood pressure as it can lead to early diagnosis of diseases that may be linked to high or low blood pressure. PTT is the time taken by the arterial pulse propagating from the heart to a peripheral site. This can be calculated from ECG signals and PlethysmoGram signals. Since, PTT has been found to be correlated to Blood Pressure, it is imperative to calculate PTT accurately. In this paper, algorithms used to calculate the points of interest in the ECG signal and the signal along with the calculation of PTT from them is developed. The coding has been done in LabVIEW which is has a graphical programming syntax that makes it simple to visualize, create, and code engineering systems.

Index Terms—Blood Pressure, ECG,PTT,PPG, LabVIEW

I. INTRODUCTION

Blood Pressure is the pressure exerted by blood on the walls of arteries. There are two values of blood pressure for a person at a particular instant, the Systolic blood pressure and the Diastolic blood pressure. The cardiac cycle consists of the steps from the beginning of one heart beat to the end and the beginning of the next heartbeat. It consists of Systole, Diastole and a gap in between. The heart consists of 4 chambers, the left and right Atria and the left and right Ventricles. Systole is when blood in the ventricles are pumped out to the body, the impure blood going from the right ventricle to the lungs and the pure blood to the body through the aorta. Following Systole, Diastole takes place when blood from the atria is moved into the ventricles. Ventricles having a larger volume, cause the blood to pushed out with a large amount of force as it has to travel all over the body through the arteries. Thus Systolic blood pressure has a higher value than Diastolic blood pressure. Thus, blood pressure is measured both as the heart contracts, i.e. systole, and as it relaxes, i.e. diastole. Normal blood pressure is considered to be a systolic blood pressure of millimetres of mercury and diastolic pressure of 80 millimetres of mercury (stated as "120 over 80"). Consistent Blood Pressure readings above the maximum value and below the minimum value is known as High Blood Pressure and Low Blood Pressure respectively. Both are damaging to the health of an individual especially high blood pressure in the long run, even though they may go undetected in the early stages. Regular checks of blood pressure is important and this leads to resarch in different ways to effectively calculate blood pressure which does not need the patient to visit the doctor frequently. The method using PlethysmoGram to indirectly calculate blood pressure is interesting in this respect.

Pulse Transit Time (PTT) is the time taken taken by the arterial pulse pressure wave to propagate from the point of origin which is the aortic valve to a peripheral site. The point of origin is the aortic valve from where the blood is pumped out via the left ventricle. Thus PTT can also be said to be the interval between ventricular electrical activity and the peak of pulse wave taken at a peripheral site. Calculation of PTT will be further enumerated in section II B. Pulse Transit Time is a useful marker which can be used to indicate arterial stiffness as well as cardiac output amongst other cardiovascular indices. It can also be used to estimate blood pressure. Pulse Wave Velocity (PWV) is the speed of a pressure pulse propagating along the arterial wall[2]. Since speed is inversely proportional to time, the Pulse Wave Velocity for the pressure pulse propagating along the arterial wall from the heart till a peripheral point can be calculated from the Pulse Transit Time which is the time taken by the same pressure pulse to move from the aorta to the peripheral site. Pulse Wave Velocity is related to blood pressure as a result of which the Pulse Transit Time can be used to estimate Blood Pressure given other parameters like elastic modulus of vessel wall, blood density, arterial dimensions among other parameters[1].

Pulse Transit Time has been used for a variety of applications. Pulse Transit Time has been used by Kounalakis et al. and has been shown to be related to cardiac output[3]. One of the earliest research in this area was done by Phillip Hallock where he related Pulse Wave Velocity to arterial elasticity in 1934[4].Smith et al. used the Pulse Transit Time for calculation of parameters needed for patients with sleep disorders [5]. Ochiai et al. used the Pulse Transit Time to predict blood pressure changes in canines in 1999 [6]. Ahlstrom et al. in 2005 used the Pulse Transit Time with patients undergoing Hemodialysis. Blood Pressure changes are not uncommon in patients undergoing hemodialysis and it is necessary to measure them so that the patient is not at a risk of injury due to a drop in blood pressure. He used the Pulse Transit Time to find changes in the Systolic Blood Pressure and showed that it is correlated to it for a trend-indicating system[7]. Alty et al. used the Pulse Wave Velocity technique which is derived from the photoplethysmogram to detect arterial stiffness which is indirectly related to hypertension or high blood pressure in 2007 [8]. Fechir et al. used the Pulse Transit Time to detect Sympathetic Nervous System (SNS) arousal in 2008. He used the PTT along with other cardiovascular parameters for comparison of SNS patterns during stress tasks undertaken by patients [9]. Schmalgemier et al. used the Pulse Transit Time and showed its correlation to the blood pressure under conditions of CPAP i.e. Continuous Positive Airway Pressure which is a type of ventilator [10]. Contal et al. compared Pulse Transit Time to respiratory ratio and concluded that it is promising for noninvasive assessment of inspiratory muscle effort under NIV (NonInvasive Ventilation) conditions [11]. Kortekaas et al. showed that the Pulse Transit Time is a reliable factor to assess if the axillary bracial plexus block is successful or not [12].

Chapter II describes the technique of Pulse Transit Time calculation. Chapter III describes in short the algorithms used in calculation of the ECG peaks and Plethysmogram characteristic points which are then used to calculate the Pulse Transit Time. It also has the algorithm for calculation of the Systolic and Diastolic peaks of the Blood Pressure signal.Results and Conclusion are in chapter IV and V respectively.

II. Technique

A. Current Technique

Light is made to reflect off the skin or go through it using an infrared LED. The reflected light or the transmitted light is collected by a photodiode. The waveform produced depends on the amount of blood flowing through the capillaries in the volume through which the light has passed. There are two types of plethysmography depending on whether the reflected light or the transmitted light is used. Transmittance mode plethysmography uses the transmitted light. Reflectance mode plethysmography uses the reflected light.

Change in the flow of blood which depends on the heart rate causes a change in the intensity of the light which is reflected or transmitted. Thus the amplitude of the waveform depends on the volume of blood at that particular instant in time.

There are 2 components in a plethysmogram signal. They are the AC component and the DC component. The DC component does not vary much and is dependent on the material that does not vary through which the light passes. This material is skin, cartilage, venous blood, etc. The AC component on the other hand, varies and depends on the volume of the blood at that time instant. During Systole, the volume of blood increases and due to that, the light absorbed is more resulting in less light at the receiver. During Diastole, the volume of blood is less, resulting in more light at the receiver.

Now, PTT is the time taken by the arterial pulse propagating from the heart to a peripheral site, and can be calculated as the time interval between the R wave peak of electrocardiogram (ECG) and a characteristic point of photoplethysmogram (PPG). The characteristic point can vary and a number of points on the PPG waveform can be chosen as a characteristic point.H Ma et al. used the peak of the PPG signal as the characteristic point [13]. G Zhang et al. used the diastolic foot of the PPG as the characteristic point [14]. M Gomez Garcia et al. used the halfway point between the diastolic foot and the systolic peak as the characteristic point [15]. X Ding et al. used the peak upslope i.e. the maximum of the first derivative of the plethysmogram as the characteristic point which will be used in this paper [16].

We will be using the peak of the first derivative of the plethysmogram signal as our characteristic point.

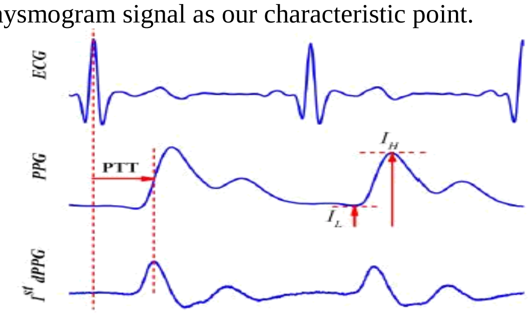


Fig 1.1 Calculation of PTT (reproduced from [1])

III. Detection of PTT and Blood Pressure

Signals of ECG and Plethysmogram are taken from the mimicdb database provided by Physionet.org.

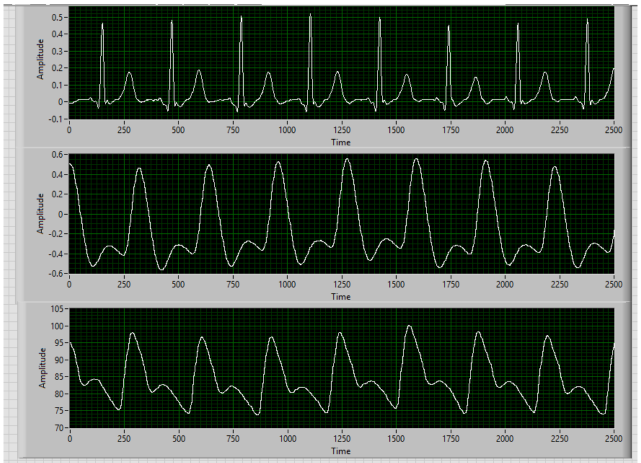


Fig 3.1 Signals ECG, PPG and Blood Pressure from mimicdb database

A. Peak Detection of the ECG Signal

In the first stage, for detection of the R-peak of the ECG signal, the signal is loaded into the LabVIEW environment. It can then be stored in an array which can be plotted using a graph indicator.The QRS region has higher frequency content, when noise has been removed. So, the derivative of the signal shows larger amplitudes around the R-peak area. This is because the digital ECG signal data points are equidistant in time. Hence, the difference in amplitude between successive data points in the QRS region are larger which result in larger amplitudes of the corresponding signal derivative as the derivative is basically the difference with respect to time.So, after the second derivative is taken and squared to make the peak of the second derivative more prominent. This peak which can easily be detected is used to find the R-peak of the original ECG signal. As shown in Fig 3.1 the ECG signal peaks are surrounded by a rectangular waveform. This is the output of the algorithm used to find the peaks, after this a simple search for the maximum in each rectangle will give the locations of the R-peaks in the ECG signal.

B. Peak Detection of Derivative of Plethysmogram

To calculate eth Pulse Transit Time, the time difference between the R-peak of the ECG and the peak of the derivative of the Plethysmogram is needed. The peak of the first derivative of the plethysmogram signal needs to be calculated. The first difference signal of the Plethysmogram signal is calculated and then it is rectified. Empirically, by observing the maximum value of the peaks in the signal a fixed threshold is taken which is taken to be about 50% of the maximum value. The algorithm searches for the maximum value which is the peak with the highest value. After its detection, its location is stored and all values within a window of 250ms around that peak is are set to zero so that in the next iteration when maximum value is searched for the same peak does not get found. The algorithm continues till no peaks are left.The result is shown in Fig. 3.2. The signal in green is the plethysmogram and the signal in white is its first derivative. The windowed signal is the result of the algorithm, the peaks of the first derivative are easily calculated by a simple maximum within each window.

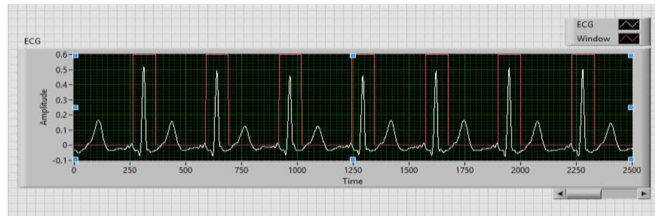


Fig. 3.1 The result of ECG R-Peak Detection

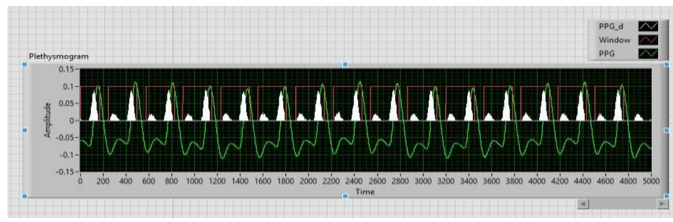


Fig 3.2 The result of the peak detection of first derivative of PPG signal

C. Systolic and Diastolic Blood Pressure Detection

For the detection of Systolic Blood Pressure and Diastolic Blood Pressure, the first derivative if the signal is taken. This will have a maximum value at the upslope of the signal i.e. before the systolic peak. The algorithm then finds the peaks similar to the way the peaks were calculated for the first derivative of the plethysmogram signal. Next, the immediate zero crossing points are calculated at the left and right of each peak. The zero crossing point on the left of the peak corresponds to the Diastolic Blood Pressure and the zero crossing point at the right corresponds to the Systolic Blood Pressure of the continuous blood pressure signal. Adding a few milliseconds for reduction in error at the ends of the zero crossing points and we get the windowed signal centered at each peak as shown in white in figure 3.3. The SBP and DBP values can then easily be found out by finding the maximum and the minimum in each rectangular window. Fig. 3.3 shows the blood pressure signal in green while its first derivative is shown in red.

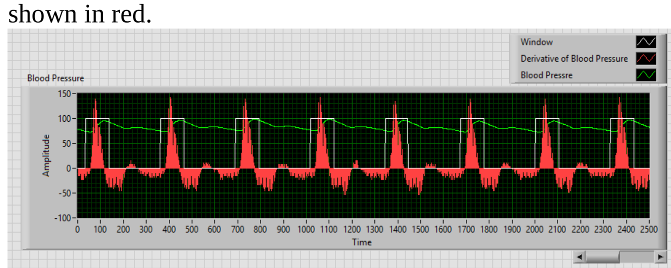


Fig. 3.3 Calculation of SBP and DBP from the Blood Pressure Signal

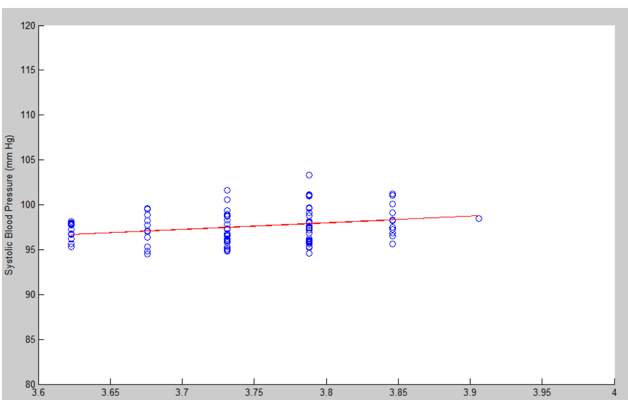
IV. RESULTS

The Pulse Transit Times were found out from the results of the peak detection of the ECG and the first derivative of the plethysmogram signals. Since the Pulse Transit Time is negatively correlated to Blood Pressure, the inverse of the Pulse Transit Time was taken. NonLinear Regression Analysis was carried out between calculated values of the inverse of the Pulse Transit Time(called PWV for simplicity) and the Systolic Blood Pressure values. The resulting curve is shown in Fig 4.1.

The scatter plot shows the values of Systolic Blood Pressure for the values of PWV. While the fitted plot in red shows the relation between SBP and PWV. It can be seen that as the Velocity increases or as the Pulse Transit Time decreases, the Blood Pressure value is higher. The equation used for fitting was

$$SBP = a \times PWV^2 \pm b$$

The form of the equation was in line with that used by Wibmer et al. [17]. On regression analysis, the calculated values of a was 83.98 and b was positive 0.97. Normalized RMSE value was found to be 0.2.



V. CONCLUSION

PTT was calculated from the ECG and PPG signals and compared with the calculated values of Blood Pressure. Using Regression analysis, the data points of the blood pressure were fitted to the inverse of Pulse Transit Time values resulting in a non-linear curve. The Systolic Blood Pressure was found to increase with decrease in Pulse Transit Time as expected.

REFERENCES

[1] Ding, X., Zhang, Y., Liu, J., Dai, W. and Tsang, H. (2016). Continuous Cuffless Blood Pressure Estimation Using Pulse Transit Time and Photoplethysmogram Intensity Ratio. *IEEE Transactions on Biomedical Engineering*, 63(5), pp.964-972.

[2] Gesche, H., Grosskurth, D., Küchler, G. and Patzak, A. (2011). Continuous blood pressure measurement by using the pulse transit time: comparison to a cuff-based method. *European Journal of Applied Physiology*, 112(1), pp.309-315.

[3] Kounalakis, S. and Geladas, N. (2009). The Role of Pulse Transit Time as an Index of Arterial Stiffness During Exercise. *Cardiovascular Engineering*, 9(3), pp.92-97.

[4] HALLOCK, P. (1934). ARTERIAL ELASTICITY IN MAN IN RELATION TO AGE AS EVALUATED BY THE PULSE WAVE VELOCITY METHOD. *Archives of Internal Medicine*, 54(5), p.770.

[5] Smith, R., Argod, J., Pepin, J. and Levy, P. (1999). Pulse transit time: an appraisal of potential clinical applications. *Thorax*, 54(5), pp.452-457.

[6] OCHIAI R, TAKEDA J, HOSAKA H, SUGO Y, TANAKA R, SOMA T: The relationship between modified pulse wave transit time and cardiovascular changes in isoflurane anesthetized dogs. J ClinMonitComput 15: 493-501, 1999.

[7] AHLSTROM C, JOHANSSON A, UHLIN F, LÄNNE T, ASK P: Noninvasive investigation of blood pressure changes using the pulse wave transit time: a novel approach in the monitoring of hemodialysis patients. J Artif Organs 8: 192-197, 2005.

[8] S. Alty, N. Angarita-Jaimes, S. Millasseau and P. Chowienczyk, "Predicting Arterial Stiffness From the Digital Volume Pulse Waveform", IEEE Transactions on Biomedical Engineering, vol. 54, no. 12, pp. 2268-2275, 2007.

[9] Fechir M, Schlereth T, Purat T, Kritzmann S, Geber C, Eberle T, Gamer M, Birklein F: patterns of sympathetic responses induced by different stress tasks. openneurol j 2: 25-31, 2008.

[10] Schmalgemeier H, Bitter T, Bartsch S, Bullert K, Fischbach T, Eckert S, Horstkotte D, Oldenburg O: pulse transit time: validation of blood pressure measurement under positive airway pressure ventilation. sleep breath 16: 1105-1112, 2012.

[11] Contal O, Carnevale C, Borel J-C, Sabil A, Tamisier R, Lévy P, Janssens J-P, Pépin J-L: pulse transit time as a measure of respiratory effort under non-invasive ventilation. eurrespir j 41: 346-353, 2013.

[12] KortekaasMc, NiehofSp, Van VelzenMhn, Galvin Em, HuygenFjpm, StolkerRj: pulse transit time as a quick predictor of a successful axillary brachial plexus block. ActaAnaesthesiolScand 56: 1228-1233, 2012.

[13] Ma, H. (2014). A Blood Pressure Monitoring Method for Stroke Management. *BioMed Research International*, 2014, pp.1-7.

[14] Zhang, G., Liu, C., Ji, L., Yang, J. and Liu, C. (2016). Effect of a Percutaneous Coronary Intervention Procedure on Heart Rate Variability and Pulse Transit Time Variability: A Comparison Study Based on Fuzzy Measure Entropy. *Entropy*, 18(7), p.246.

[15] Gómez García, M., Troncoso Acevedo, M., Rodriguez Guzmán, M., Alegre de Montaner, R., FernándezFernández, B., del Río Camacho, G. and González-Mangado, N. (2014). Can Pulse Transit Time Be Useful for Detecting Hypertension in Patients in a Sleep Unit?.*Archivos de Bronconeumología (English Edition)*, 50(7), pp.278-284.

[16] Ding, X., Zhang, Y. and Tsang, H. (2016). *Impact of heart disease and calibration interval on accuracy of pulse transit time–based blood pressure estimation. Physiological Measurement*, 37(2), pp.227-237.

[17] T. Wibmer, et al., "*Pulse transit time and blood pressure during cardiopulmonary exercise tests*," Physiol. Res., vol. 63, pp. 287-296, 2014.