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Methodological Role of Mathematics to Estimate Human Blood Pressure through Biosensors

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Abstract: This paper presents a non-invasive technique and cuff less method for blood pressure measurement with a hardware prototype implementation. The sophisticated feature called pulse transit time (PTT) is extracted and investigated with a development of a smart system which consists of ECG, PPG sensor to measure the variation of systolic and diastolic blood pressure with support of advanced signal processing methodologies. The proposed method experiments have been carried out in hospital environment and tested with real time patients to validate the proposed method. The maximum error percentage of the proposed system has been shown to be 5.3% of systolic blood pressure (mmHg) and 4.7% of diastolic blood pressure (mmHg). This system also allows the monitoring of patient hypertension and overcome the limitation of cuff-based hospitalized measurement system.

Keywords: ECG signal, wavelet detrend, blood pressure, signal processing

1. Introduction

In healthcare networks, different biomedical signals are considered for various vital parameters measurement. These signals such as ECG signal, EEG signal, PPG and EMG signal which are acquired from different types of biomedical sensors. Although the large number of numerous studies have been investigated by many researchers to provide the solution about the inconvenience caused by commercial blood pressure equipment. In human life, due to increasing the economic, population and every day activities induced many health-related issues such as cardiovascular diseases, brain problems, nervousness, hypertension and stress (L. Wang et.al. 2015). The research says that these disease in human life affects the health of the people (17.3 million deaths per year in 2013) (B. Ibrahim et.al., 2019). Now a days, these problems can be identified with immediate analysis of patient vital parameters such as heart rate, pulse rate, SpO2 and blood pressure (R. Jegan, 2018, 2017, Y. Zheng et.al., 2014). In this modern world, people are so much stressed off with their daily routines such as official duties and household chores. They even forget to take care of their own health condition. This often leads to hypertension or increased blood pressure. The term high blood pressure leading an important health issue in society and basically, it affects many adults around the world.

Many researchers have investigated the cardiovascular mortality by analyzing the blood pressure during different time (Masahiro Kikuya et.al., 2010, Eamon Dolan et.al., 2005, Y. Zhang et.al., 2013). Usually equipment used to measure blood pressure are relatively heavy. In hospital environment, the measurement of blood pressure can be done by a sphygmomanometer equipment using an inflatable cuff. These methods are enduring discomfort in terms of vessel compression process and materials (inflatable cuff) attached with patient hand produces discomfort (G. Ogedegbe et.al., 2010). Measuring blood pressure gives detail perspective view of individual health condition. Also, it gives to measure heart rate variability, pulse rate and usefully indicates cardiovascular diseases (S. Ahmad et.al., 2010). The most

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dynamic limitations in blood pressure measurement involves inappropriate cuff size and position, reliance on blood flow. Therefore, cuff less devices are needed in healthcare environment to obtain long term blood pressure measurement during every human activity. To overcome the problem arises by cuff-based measurement, PPG and ECG based approach has been play an important role for finding blood pressure (A. M. Johnson et.al., 2017).

Recently, the non-invasive device plays a main role to measure blood pressure by using biosensors. Due to growing need for biomedical research, the involvements of different sensors are investigated and available to the developer for characterizing the behavior of biosignals. Among those, the ECG and PPG sensors are widely applicable for acquiring ECG and PPG signal (Arthi, 2014, M. Bolanos et.al. 2006, H. J. Baek et al., 2012, R. Jegan et.al., 2013, 2015, S. Ahmad et.al., 2010). Many of the researchers have already investigated on importance of blood pressure measurement (J. Foo et.al., 2006, H. Gesche et.al., 2011, J. Huttunen et.al., 2019, L. Sornmo et.al., 2012, X. He et.al. 2014, R. Jegan et.al., 2020). The non-invasive method consists of ECG and PPG sensor with advanced signal processing algorithms are mainly used in the field of biomedical environment and also applicable for home based monitoring purpose. Among the variety of studies on blood pressure estimation, pulse transit time (PTT) is considered as an effective method and its response is closely related to arterial stiffness (M. Gao et.al., 2017, R. Mukkamala et.al., 2015, Q. Liu et.al., 2011). The measurement of systolic and diastolic blood pressure gives an easy identification of systolic hypertension of the patients. Both, systolic and diastolic blood pressures are useful for monitoring human heart. Apart from this, the non-invasive imaging tools such as optical coherence tomography (OCT) and optical coherence tomography angiography (K M Ratheesh., 2016, Ratheesh Kumar, 2015, 2019) for the depth resolved imaging of blood vessels and their flow analysis. These approaches have been widely adopted and treated as gold standard in ophthalmology, cardiovascular, skin/tissue diagnostic imaging. In blood pressure measurement, there are some commercially available devices are used for measuring systolic and diastolic blood pressure in hospital environment. The present works mentioned in this paper are originated from the application of signal processing technique for measurement of blood pressure from PTT (L. Di Marco et.al. 2011). The proposed paper targets the development of smart measurement system which consists of ECG, PPG sensor for easy acquisition of real time signal to measure blood pressure. The proposed system also consists of statistics and machine learning approach for estimating blood pressure from the features extracted from ECG and PPG signal. The structure of this paper is made as follows: section 2 presents a technique on measuring blood pressure, while section 3 presents experimental results and section 4 summarize the conclusion of the paper.

2. Materials and Methods

The various literature papers highlight current uses of various methods for measuring human blood pressure from biomedical signal Y. Choi, et.al., 2013, M. Kachuee et.al., 2017, Yali Zheng et.al., 2014, V. Chandrasekaran et.al., 2013, C. Kim et.al., 2015, M. Forouzanfar et al., 2013). Sensor based biomedical signal acquisition and processing is more important for diagnosing many human diseases. The smart electrodes based front end acquisition and pre-processing units are used to obtain quality signal for an accurate measurement.

The advances in sensor technology and biomedical research lead to affordable, miniaturized, low power, high performance smart sensing system for measuring many vital parameters. The purpose of this article is to provide an efficient way which includes ECG and PPG signal acquisition and mechanism for blood pressure measurement. This section of the paper is structured to provide an information and methods incorporated with biomedical signal processing which gives information about the various components involved for development of blood pressure measurement systems

2.1 Sensors for signal acquisition

Basically, the system used for acquiring PPG signal can be done by a sensor which measures light absorption changes during heart pumping actions. PPG signal helps in determining the blood volume changes in the body. PPG sensor consists of the clip which has a LED light with 860nm wavelength in it. This clip is placed at the tip of the finger. The light from the LED is made to pass through the tip of the finger and it is transmitted or reflected back and received by the photodiode. The reason for using LED light with 860nm lies on the strong penetration into the tissue which gives better response. This reflected light gives pulse rate of that particular person. This paper proposed a method in which ECG signal is acquired by attaching the ring electrodes on the skin. Normally ECG signal describes the depolarizing and repolarizing of the heart mechanism. The wave pattern of the ECG signal consists of P wave, QRS complex and T wave. Three electrodes are connected, one electrode is used as a reference and the other two electrodes act as working electrodes.

2.2 Data processing module

The data processing module made up of amplifier and filter in which ECG and PPG signals are collected from the sensors and given to this module. The signal measured by sensor lies on very low amplitude with the frequency range of 0.05Hz to 100Hz and 0.1Hz to 5Hz respectively. The signal acquisition system should have protection against interference effects to facilitate the identification of weak ECG and PPG signals. The electrodes are connected to the amplifier (instrumentation amplifier INA331). The gain of the instrumentation amplifier can be adjusted by varying gain resistor. It should be greater than 5 according to the equation, G = 5+5(R2/R1). Basically, the sensor outputs are typically very low in range, it is necessary to use preamplifier circuitry to further process the received signals. As a photodiode is employed in the PPG sensor in the circuit and it requires linear current response over a wide range of light input. The signal conditioning circuit used to amplify the bio signals are given below.

The NI myDAQ is also interfaced between the data processing module and analyzing environment which gives the ability to measure and analyses bio signals with 500 samples per second. The moving average filter is implemented in this paper to remove the noises from the signals. The moving average filter performs its operation by averaging a total available number of points from the input signal to produce each point in the output signal. It takes 1000 number of points for performing its action in terms of removing noises as shown in Fig. 6. Mathematically, the function of this filter is expressed as,

$$MAFj = y(i) = \frac{1}{K}\sum_{j=0}^{K-1} x(i+j) \tag{1}$$

Here, *x(i)* is the input signal need to be filtered out, *y(i)* is the moving average filter output signal, and K is the number of averaging points.

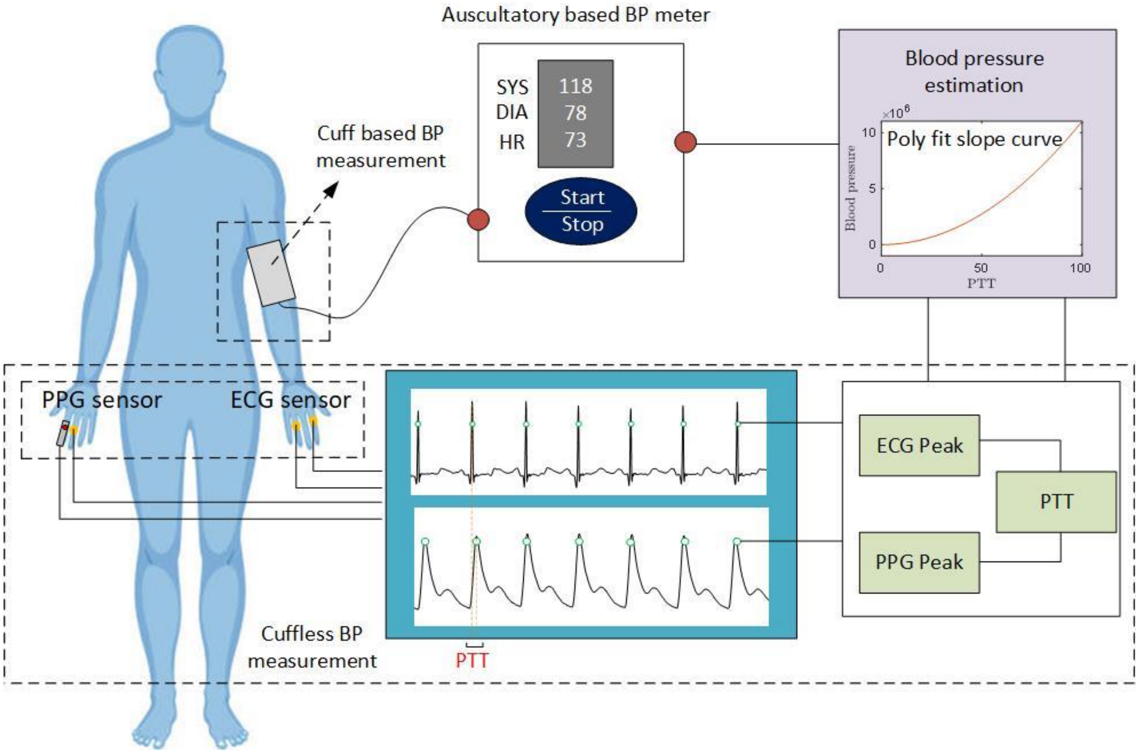


Fig. 1 - Proposed system architecture for blood pressure measurement system

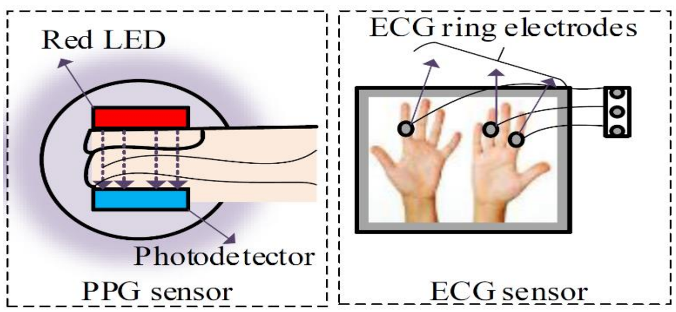


Fig. 2 - PPG and ECG sensor configuration for signal acquisition

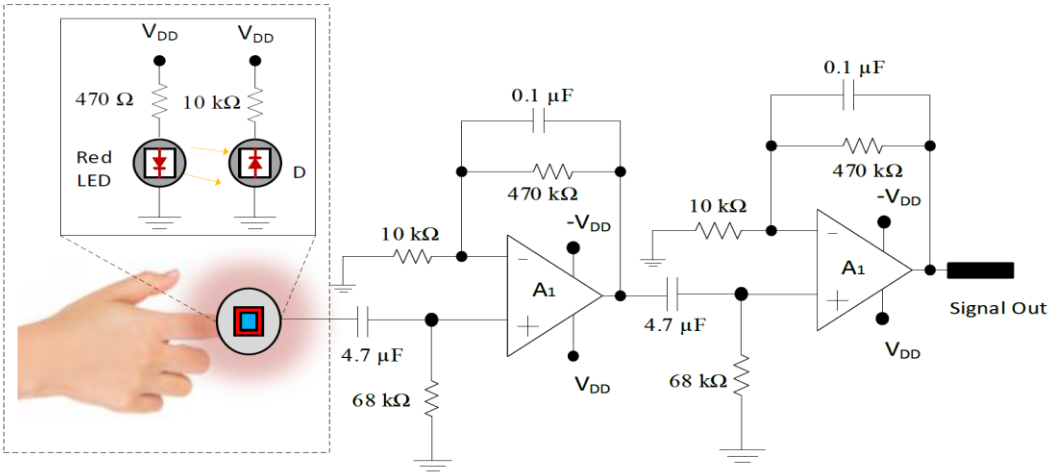


Fig. 3 - Bio signal conditioning circuit design

2.3 Peak detection and PTT estimation

The accurate peak detection in ECG and PPG signal is an essential factor for measuring blood pressure from the biomedical signals. However, these techniques suffer from many biological parameters including noise. The methodology for peak detection involves four stages. The first stage includes a low pass filter, an amplitude normalization and first-order forward difference operation to emphasize the peak in ECG and PPG signal, and to attenuate the high frequency signal and only allows low frequency signals. In the second stage, wavelet analysis detrend is used to removal the baseline drifts. In the third stage, the peak detector involves to detect the number of peaks in the ECG and PPG signals. In the fourth stage, threshold value is set to find the true peak. The proposed method gives the estimation of an accurate locations of the signal peaks. Once peak location is found, it is converted into peak time by multiplying the location with the sampling frequency to estimate PTT.

2.4 Blood pressure estimation

The estimation of blood pressure can be done by many numerical mathematical modeling. Here, the mathematical differential equations are derived from the features of ECG and PPG signal (Peak amplitude and PTT) and regression mathematical model is applied to find the slope which gives the exact estimation of blood pressure from the acquired signal. The regression principle can be applied with direct comparison of values measured by standard devices (Digital sphygmomanometer). The SBP (Systolic Blood Pressure), DBP (Diastolic Blood Pressure) slope curve can be obtained by correlating the values of PTT with the standard values obtained from reference devices.

$$SBP = y(i) = 1108.9x^2 - 665.47x + 206.18 \quad (2)$$

$$DBP = z(i) = 275.5x^2 - 190.4x + 105.9 \quad (3)$$

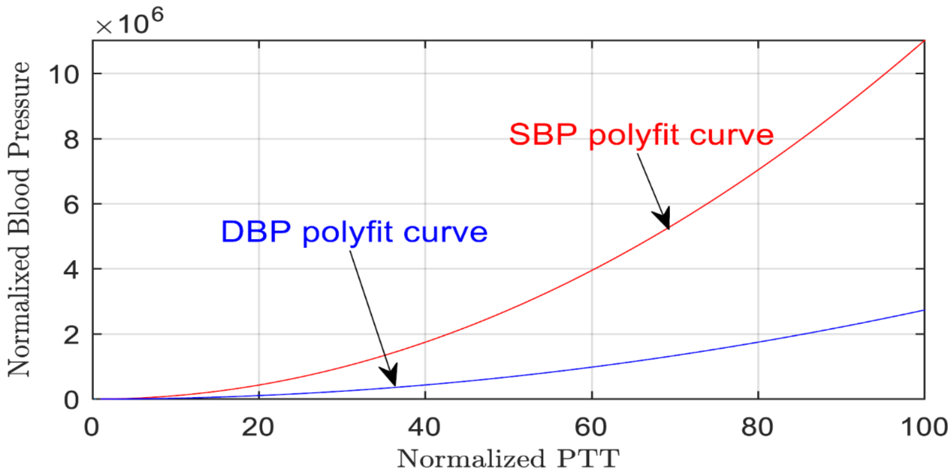


Fig. 4 - Blood pressure estimation slope curve

Figure. 4 shows that the blood pressure estimation slope curve which can be obtained from the machine learning and statistical signal processing approach. Both systolic and diastolic blood pressure values are obtained from reference devices and corresponding PTT values are measured and used for training the system. Figure. 5 provides the detailed perspective view for developing cuff less blood pressure measurement system and methodologies adopted for extracting desired features from an ECG and PPG signal.

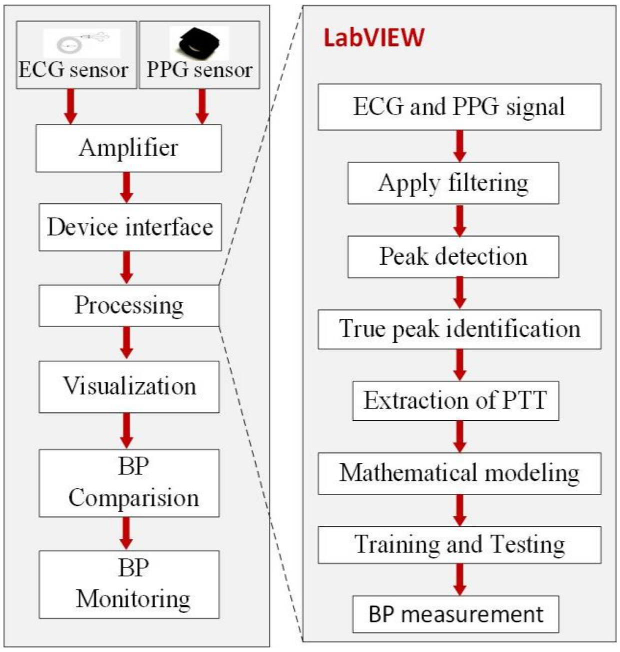
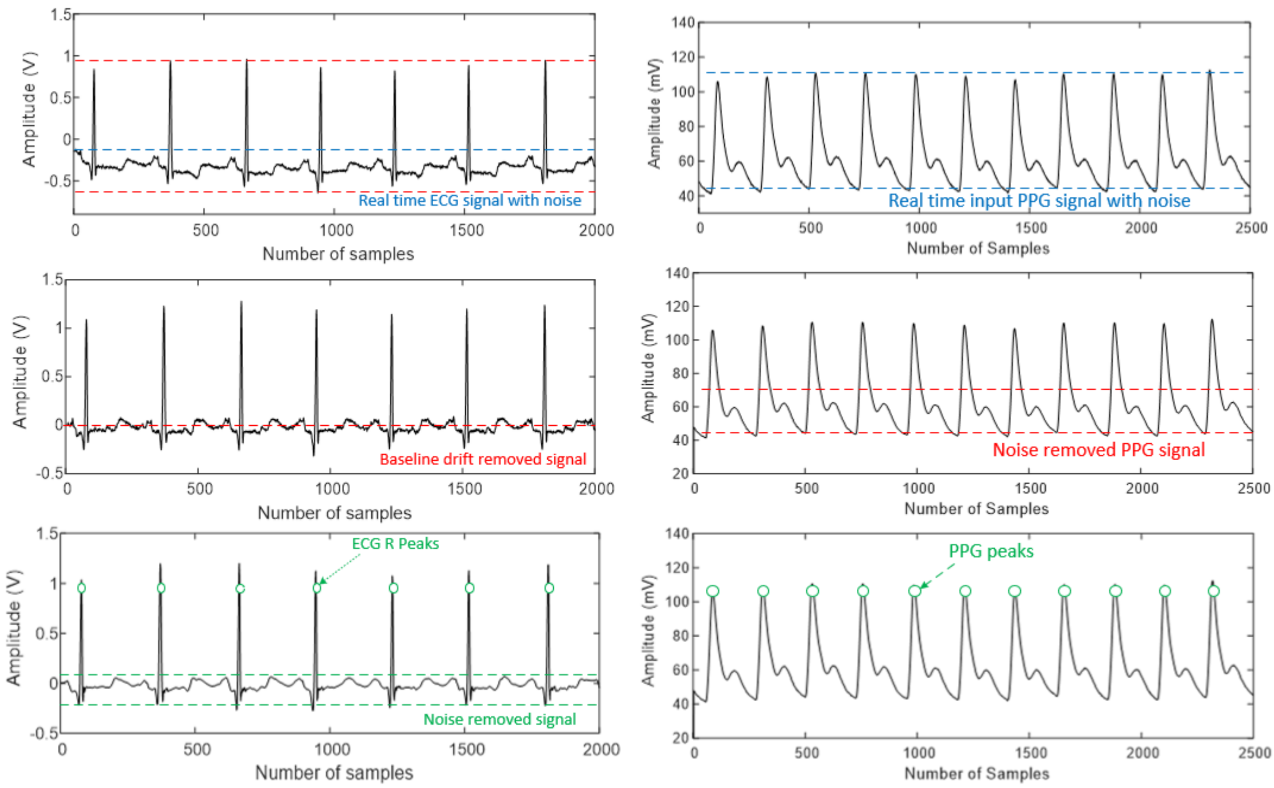


Fig. 5 - Measurement system flow diagram depicting blood pressure measurement

3. Results and Analysis

As mentioned in the introduction section, this modern society often leads to more and different type of health issues. Among these problems, hypertension leads an important and affects many humans. Clinically, it is important to keep a regular check on blood pressure because it determines patient health directly. The measurement of blood pressure can be done in different ways, the most one is manual method (using level of mercury based) and the other is machinery method (digital measurement). Basically, non-invasive method of blood pressure measurement is done by two method. One is of intermittent method which is not so liable always and the other one is continuous method. If a patient is needed to be kept under monitor for the measurement of blood pressure for prolonged period of time then intermittent measurement cannot be handy. In such cases, continuous measurement of blood pressure is necessary to monitor blood pressure for a long period of time.

In this paper, a signal collection module collects both the PPG and ECG signals. Electrode gel is used to get better accuracy by placing the electrodes in the correct spot and also for better contact of electrodes with the skin. After filtering and wavelet detrend applied on the patients signal to remove the signal drift, the soft threshold peak detector has been applied on the signal and gives the true peak detection from the signal. From these peaks, pulse transit time is estimated and the respective relationship between BP and PTT is analyzed and has been used to estimate the Systolic Blood Pressure (SBP) and Diastolic Blood Pressure (DBP). The Experimental results for ECG, PPG signal processing are given in Figure. 6. Sensor with both LED and photodiode are used for acquiring PPG signal. The signals are detected by the photodiode and its output is converted to voltage by a signal conditioning circuit, and is given to the data acquisition system. The acquired analog signals are taken into the processing unit to find the location of its peak in real time basis. The subjects were considered for this study between the ages of 19-41. The signals from the real time subjects were collected and stored for about a minute with relaxed condition. The commercial blood pressure device (BP meter) is also used for collecting the pressure readings for validation. The machine learning and statistical data analysis was performed in simulation environment. From the obtained PTT, mathematical modeling has been derived through regression principle. The result obtained from the software has been shown in Table.1. It also indicates the accuracy of the proposed method by comparing with reference devices. Further, the large number of measurements have been taken and used for training the system to maximize the system output and reduce the error rate. Here, PTT measurement is performed with real time ECG and PPG signal and the blood pressure measurement is done through offline mode after measuring PTT from ECG and PPG signal, standard systolic and diastolic blood pressure values from reference devices.



(a). Measurement results on ECG signal processing (b). Measurement results on PPG signal processing

Fig. 6 - Experiment results for ECG, PPG signal processing and feature extraction

Table 1 - Training results obtained from PTT for blood pressure measurement

Subjects	Age	PTT (s)	Reference BP SBP (mmHg)	Reference BP DBP (mmHg)	Estimated BP SBP (mmHg)	Estimated BP DBP (mmHg)	Error % SBP (mmHg)	Error % DBP (mmHg)
S1	21	0.294	94	63	106.38	73.70	-13.1	-16.98
S2	20	0.3752	109	68	112.61	73.21	-3.31	-7.66
S3	21	0.2515	116	78	108.95	75.40	6.076	3.32
S4	21	0.3422	110	72	108.31	72.97	1.529	-1.35
S5	23	0.3573	110	70	109.98	73.00	0.013	-4.29
S6	21	0.3714	108	81	111.98	73.15	-3.690	9.68
S7	20	0.3799	97	66	113.41	73.29	-16.91	-11.05
S8	20	0.2902	100	74	106.44	73.81	-6.446	0.25
S9	20	0.3864	106	56	114.61	73.43	-8.130	-31.12
S10	18	0.3900	130	84	115.32	73.51	11.29	12.48
S11	18	0.3197	106	86	106.76	73.15	-0.726	14.93
S12	18	0.3440	112	64	108.49	72.97	3.13	-14.01
S13	18	0.3823	115	80	113.84	73.34	1.008	8.32
S14	41	0.3505	139	92	109.17	72.97	21.46	20.67
S15	40	0.3701	111	80	111.79	73.13	-0.716	8.57
S16	18	0.3543	105	68	109.60	72.99	-4.390	-7.34
S17	18	0.3408	108	65	108.18	72.97	-0.170	-12.27

The below Figure 7. shows that the prediction interval for estimating blood pressure from pulse transit time. Table. 2. shows a clinical experiment carried out in the hospital after training the system to validate the performance of proposed method by tracking blood pressure variations. Six healthy young subjects without cardiovascular disease were considered for this experiment. Throughout the experiment procedures, ECG and PPG signals were recorded by sensors and their continuous BP parameters were recorded by cuff based digital sphygmomanometer.

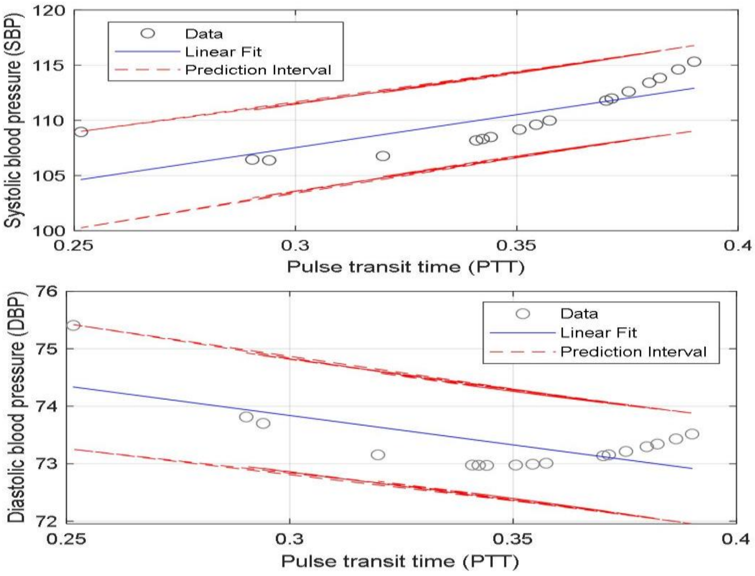


Fig. 7 - PTT Vs Estimated blood pressure linear fit curve along with prediction interval. PTT is measured in terms of seconds

Table 2 - Real time testing results obtained from PTT for BP measurement in hospital environment

Subjects	Age	PTT (s)	Reference BP SBP (mmHg)	Reference BP DBP (mmHg)	Estimated BP SBP (mmHg)	Estimated BP DBP (mmHg)	Error % SBP (mmHg)	Error % DBP (mmHg)
S1	21	0.307	106.39	73.37	109	77	2.388	4.70
S2	21	0.353	109.48	72.98	110	73	0.470	0.017
S3	21	0.403	118.27	73.90	115	71	-2.849	-4.092
S4	21	0.228	111.97	76.72	116	78	3.469	1.629
S5	21	0.380	113.53	73.30	114	72	0.407	-1.818
S6	21	0.337	107.92	72.9	114	76	5.325	3.973

Figure 8 gives the comparative analysis of measured systolic blood pressure with reference hospitalized devices. The reference blood pressure and ECG, PPG signals are taken at a same time.

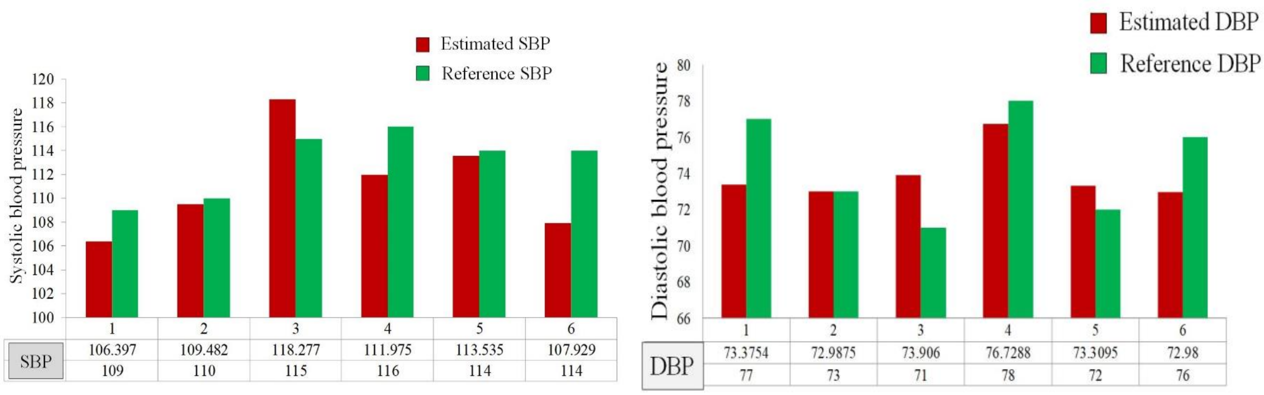


Fig. 8 - Comparison of systolic and diastolic blood pressure with reference values

From the measurement results, it was concluded that the proposed method has more advantages than the existing method used in hospital. The devices used in the hospital works based on observing Korotkoff sounds by medical providers. Also, the existing devices need a dedicated person to take measurement; it is not an automatic measurement system. Moreover, the devices used in the hospital has cuff wrapped in the arm to measure blood pressure which cannot applicable for long term continuous measurements. The proposed ECG and PPG sensor-based blood pressure measurement can be used to estimate blood pressure continuously and easy to integrate with wearable devices for long term vital parameter monitoring applications. Figure. 8 shows the comparative representation of proposed method by plotting reference systolic and diastolic blood pressure with estimated blood pressure. From the results, it was observed that the proposed non-invasive method produced the measurement of blood pressure with maximum error rate of 5.32 % in SBP and 4.70% in DBP when compared with hospitalized equipment.

4. Conclusion

This study focused on the development of non-invasive biomedical measurement system with ECG and PPG sensor for measuring blood pressure. The proposed method can provide measurements of systolic and diastolic blood pressure with low degree of error rate but has many advantages than other wearable device. In this work, an algorithmic approach is implemented to measure systolic and diastolic blood pressure. The front-end acquisition module consists of ECG and PPG sensors to estimate PTT and BP measurement. The validation of this BP estimation method was performed using commercially available devices. The proposed statistical and machine learning approach also increases the estimation accuracy and this can be consider as home based measurement device to measure continuous blood without using cuff.

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References

[1] Arthi, R.Jegan, Embedded Based Patient’s Vital Sign Monitoring System using Wireless Methods, International Journal of Engineering Research & Technology, 3(4), (2014), 835-837.

[2] B. Ibrahim, R. Jafari, Cuff less 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 13 (6) (2019) 1723–1735.

[3] C. Kim, A. M. Carek, R. Mukkamala, O. T. Inan, J. Hahn, Ballistocardiogram as proximal timing reference for pulse transit time measurement: Potential for cuff less blood pressure monitoring, IEEE Transactions on Biomedical Engineering 62 (11) (2015) 2657–2664.

[4] Eamon Dolan, Alice Stanton, Lut Thijs, Kareem Hinedi, Neil Atkins, Sean McClory, Elly Den Hond, Patricia McCormack, Jan A. Staessen, Eoin O Brien, Superiority of ambulatory over clinic blood pressure measurement in predicting mortality, Hypertension 46 (1) (2005) 156–161.

[5] G. Ogedegbe, T. Pickering, Principles and techniques of blood pressure measurement, Cardiology Clinics 28 (4) (2010) 571–586.

[6] H. Gesche, D. Grosskurth, G. Kuchler, A. Patzak, Continuous blood pressure measurement by using the pulse transit time: comparison to a cuff-based method, Eur J Appl Physiol. 112 (1) (2011) 309–315.

[7] H. J. Baek, G. S. Chung, K. K. Kim, K. S. Park, A smart health monitoring chair for nonintrusive measurement of biological signals, IEEE Transactions on Information Technology in Biomedicine 16 (1) (2012) 150–158.

[8] Jegan & WS Nimi, Sensor Based Smart Real Time Monitoring of Patients conditions Using Wireless Protocol, International Journal of E-Health and Medical Communications (IJEHMC), 9(3), (2018), 79-99.

[9] J. Foo, S. Wilson, G. Williams, M. Harris, D. Cooper, Measurement of pulse transit time using at90s8535 microcontroller, Measurement 39 (6) (2006) 505 – 511.

[10] J. Huttunen, L. Karkkainen, H. Lindholm, Pulse transit time estimation of aortic pulse wave velocity and blood pressure using machine learning and simulated training data, PLoS Comput Biol. 15 (8) (2019) e1007259.

[11] K M Ratheesh et al, Spectral phase-based automatic calibration scheme for swept source-based optical coherence tomography systems, Phys. Med. Biol. 61(2016) 7652.

[12] L. Di Marco, L. Chiari, A wavelet-based ECG delineation algorithm for 32-bit integer online processing, BioMed Eng OnLine 10 (23) (2011) 10–23.

[13] L. Sornmo, F. Sandberg, E. Gil, K. Solem, Noninvasive techniques for prevention of intradialytic hypotension, IEEE Rev Biomed Eng. 5 (2012) 45–59.

[14] L. Wang, T. Chen, K. Lin, Q. Fang, S. Lee, Implementation of a wireless ECG acquisition SOC for IEEE 802.15.4 (zigbee) applications, IEEE Journal of Biomedical and Health Informatics 19 (1) (2015) 247–255.

[15] M. Bolanos, H. Nazeran, E. Haltiwanger, Comparison of heart rate variability signal features derived from electrocardiography and photoplethysmography in healthy individuals, in: 2006 International Conference of the IEEE Engineering in Medicine and Biology Society, 2006, pp. 4289–4294.
[16] M. Forouzanfar, S. Ahmad, I. Batkin, H. R. Dajani, V. Z. Groza, M. Bolic, Coefficient-free blood pressure estimation based on pulse transit time–cuff pressure dependence, IEEE Transactions on Biomedical Engineering 60 (7) (2013) 1814–1824.
[17] M. Gao, H. Cheng, S. Sung, C. Chen, N. B. Olivier, R. Mukkamala, Estimation of pulse transit time as a function of blood pressure using a nonlinear arterial tube-load model, IEEE Transactions on Biomedical Engineering 64 (7) (2017) 1524–1534.
[18] M. Johnson, R. Jegan, X. A. Mary, Performance measures on blood pressure and heart rate measurement from PPG signal for biomedical applications, in: 2017 International Conference on Innovations in Electrical, Electronics, Instrumentation and Media Technology (ICEEIMT), 2017, pp. 311–315.
[19] M. Kachuee, M. M. Kiani, H. Mohammadzade, M. Shabany, Cuff less blood pressure estimation algorithms for continuous health-care monitoring, IEEE Transactions on Biomedical Engineering 64 (4) (2017) 859–869.
[20] Masahiro Kikuya, Atsushi Hozawa, Takayoshi Ohokubo, Ichiro Tsuji, Mari Michimata, Mitsunobu Matsubara, Masahiro Ota, Kenichi Nagai, Tsutomu Araki, Hiroshi Satoh, Sadayoshi Ito, Shigeru Hisamichi, Yutaka Imai, Prognostic significance of blood pressure and heart rate variabilities, Hypertension 36 (5) (2000) 901–906.
[21] Q. Liu, C. Poon, Y. Zhang, Time–frequency analysis of variabilities of heart rate, systolic blood pressure and pulse transit time before and after exercise using the recursive autoregressive model, Biomedical Signal Processing and Control 6 (4) (2011) 364 – 369.
[22] R. Jegan, K. V. Anusuya, High-performance ECG signal acquisition for heart rate measurement, International Journal of Biomedical Engineering and Technology 12 (4) (2013) 371–381.
[23] R.Jegan, Nimi, Jino Ramson " Sensor based biomedical frame work for monitoring patient vital parameters" IEEE International conference on Circuits and Systems, pp: 96-100, 2020
[24] R.Jegan, K.V.Anusuya, Heart Signal Monitoring For Remote Patient Assistant Based On Optical Remote Sensing. Optoelectronics and Advanced Materials – Rapid Communications 9(5), (2015), 570 – 574.
[25] R.Jegan, Nimi WS, Low cost and Improved performance measures on filtering techniques for ECG signal processing and TCP/IP based monitoring using LabVIEW. IEEE 4th International Conference on Advanced computing and Communication systems, (2017)
[26] R.Jegan, K.V.Anusuya, Bio Sensor based Feature Extraction and physiological parameters measurement for Bio Medical applications, Int. J. Biomedical Engineering and Technology, 28(1) (2018), 67-80.
[27] R. Mukkamala, J. Hahn, O. T. Inan, L. K. Mestha, C. Kim, H. Toreyin, S. Kyal, Toward ubiquitous blood pressure monitoring via pulse transit time: Theory and practice, IEEE Transactions on Biomedical Engineering 62 (8) (2015) 1879–1901.
[28] Ratheesh Kumar, Meleppat, Murukeshan Vadakke Matham, Leong Keey Seah, Optical frequency domain imaging with a rapidly swept laser in the 1300nm bio-imaging window, International Conference on Optical and Photonic Engineering (icOPEN2015), 2015.
[29] Ratheesh K. Meleppat, Eric B. Miller, Suman K. Manna, Pengfei Zhang, Edward N. Pugh Jr., Robert J. Zawadzki, Multiscale Hessian filtering for enhancement of OCT angiography images, Proceedings Volume 10858, Ophthalmic Technologies XXIX; 108581K (2019).
[30] S. Ahmad, M. Bolic, H. Dajani, V. Groza, I. Batkin, S. Rajan, Measurement of heart rate variability using an oscillometric blood pressure monitor, IEEE Transactions on Instrumentation and Measurement 59 (10) (2010) 2575–2590.
[31] S. Ahmad, S. Chen, K. Soueidan, I. Batkin, M. Bolic, H. Dajani, V. Groza, A prototype of an integrated blood pressure and electrocardiogram device for multi-parameter physiologic monitoring, in: 2010 IEEE Instrumentation Measurement Technology Conference Proceedings, 2010, pp. 1244–1249.
[32] V. Chandrasekaran, R. Dantu, S. Jonnada, S. Thiyagaraja, K. Subbu, Cuff less differential blood pressure estimation using smart phones, IEEE Transactions on Biomedical Engineering 60 (4) (2013) 1080–1089.
[33] X. He, R. A. Goubran, X. P. Liu, Secondary peak detection of ppg signal for continuous cuff less arterial blood pressure measurement, IEEE Transactions on Instrumentation and Measurement 63 (6) (2014) 1431–1439.
[34] Y. Choi, Q. Zhang, S. Ko, Noninvasive cuess blood pressure estimation using pulse transit time and hilbert–huang transform, Computers & Electrical Engineering 39 (1) (2013) 103 – 111.
[35] Y. Zhang, Y. Zheng, W. Lin, H. Zhang, X. Zhou, Challenges and opportunities in cardiovascular health informatics, IEEE Transactions on Biomedical Engineering 60 (3) (2013) 633– 642.
[36] Y. Zheng, X. Ding, C. C. Y. Poon, B. P. L. Lo, H. Zhang, X. Zhou, G. Yang, N. Zhao, Y. Zhang, Unobtrusive sensing and wearable devices for health informatics, IEEE Transactions on Biomedical Engineering 61 (5) (2014) 1538–1554.
[37] Yali Zheng, B. P. Yan, Yuan-Ting Zhang, C. C. Y. Poon, An armband wearable device for overnight and cu-less blood pressure measurement, IEEE Transactions on Biomedical Engineering 61 (2014) 2179–2186.