Biomedical Engineering: Applications, Basis and Communications, Vol. 32, No. 4 (2020) 2050027 (8 pages)
DOI: 10.4015/S1016237220500271

SMARTPHONE-BASED DIAGNOSTIC MODEL FOR HYPERTENSION USING FEATURES FROM PHOTOPLETHYSMOGRAM

V. Devaki* and T. Jayanthi†,‡
*Department of Biomedical Engineering
Vels Institute of Science, Technology & Advanced Studies (VISTAS)
Pallavaram, Chennai 600117, Tamil Nadu, India
†Department of Biomedical Engineering
SRM Institute of Science and Technology Kattangulathur
Chennai 603203, Tamil Nadu, India

Accepted 16 May 2020
Published 29 July 2020

ABSTRACT

Photoplethysmography (PPG) is an optical technique which measures blood volume changes in the arterial blood using red and IR LEDs of wavelengths 660 nm and 940 nm, respectively. This paper proposes a methodology to measure the pulse rate from the video signal obtained using an LETV-LE MAX 2 mobile phone's camera and also to evaluate hypertension. The Android smartphone records the intensity of light reflected from the index finger. The recorded video is separated into red, green and blue frames. Since the red video frames returned useful plethysmographic information, they are filtered using Butterworth band-pass filter and power spectral density analysis was performed on them. The immediate peak gives the pulse rate of the respective subject. Fifteen features of pulse waveform are extracted and by performing the feature selection process, seven features are selected and they undergo classification process using a neural network. The feature selection process is performed by using the eigenvalues of the principal component analysis method. The eigenvalues obtained from this method show the degree of variation present in the data. The eigenvalue that is near or close to zero gives the principal components. The features that are selected by the feature selection process of principal component analysis method are peak interval, settling time, rise time, normalized PPG, peak-to-peak amplitude, first derivative and second derivative. While performing the classification process using a neural network, the accuracy of prediction was calculated for both the normal and hypertensive subjects.

Keywords: Photoplethysmography; Smartphone; Feature extraction; Hypertension.

INTRODUCTION

According to the Global Health Observatory (GHO) data, increased blood pressure causes an estimated death of 7.5 million people constituting 12.8% of the total deaths worldwide. In India, about 33% of urban people and 25% of rural people are hypertensive. The highest occurrence of hypertension was in the WHO region of Africa at 46% for both sexes. The prevalence of hypertension was the lowest in the Americas and it was 35% for both sexes. Men have higher prevalence than women in all WHO regions. About 55% of 17 million annual

‡Corresponding author: T. Jayanthi, Department of Biomedical Engineering, SRM Institute of Science and Technology, Kattangulathur, Chennai, Tamil Nadu, India. E-mail: jayanthi.t@ktr.srmuniv.ac.in

deaths are due to cardiovascular diseases which are linked to hypertension.[14] Early diagnosis of hypertension will prevent the number of deaths which is possible by using this method.[1] Home-care devices enhance our health emotionally and physically and also the daily living needs in a professional manner. Home-care devices provide more comfort and care to elderly people in their own pace in familiar surroundings. The physical strength of elderly people deteriorates which makes them more dependent on low-cost, easy-to-handle and convenient home-care devices. Home-care devices improve the patient experience by improving the quality of care and satisfaction.

The application of mobile phone in healthcare brings about a drastic improvement in medical sector. Android smartphone decreases the patient's inconveniences in hospitals and saves their time without disturbing their daily activities. It maintains an effective communication between patients, their caregivers and healthcare providers. The use of mobile application to measure the physiological signals of human body helps to monitor the chronic and acute ailments of patients by reducing their doctor visits and also helps to improve the diagnostic accuracy. It can be used in the emergency situation and can be accessed from everywhere.[2–4]

Plethysmographs are instruments which are used in the detection of pulse pressure and arterial pulse waveforms in the extremities. Most of the plethysmograph techniques available record a change in the blood volume as a blood pressure measurement.[5,6] The pulse pressure traveling through the heart vessels causes a displacement in the vessel wall. This pressure is measured at various points in the extremities.

Methods

Methods employed to detect the changes in blood volume are as follows:

- Electrical impedance changes.
- Optical changes (photoelectric method).
- Strain gauge or microphone (mechanical).

Among these methods, the one that is most commonly used to detect pulsatile change in the blood volume is the optical changes or photoelectric method.[5]

The methods that are commonly used are:

- Reflectance method.
- Transmittance method.

Transmittance method

In the transmittance method, the light from the LED is transmitted and detected using a photodetector at the other end. This is the most suited one to the areas of the body that allow light to easily pass through them, e.g. ear lobe or fingers. The bones and muscles will become an obstacle for this kind of configuration. Hence it cannot be used in any other areas of the body.

Reflectance method

In this method, a photodetector and LEDs are used on the same side to detect the light reflection by the tissues. It is a useful method in areas where the arteries are available just very close to the surface of the skin.[6]

The measurement of blood pressure, which is done by using the cut-off-based technique, helps in the early diagnosis of cardiovascular diseases. The blood pressure and PPG are widely related where the features of PPG help in the prediction of hypertension categories including pre-hypertension and hypertension. This is done because the morphological information of PPG varies depending on the blood pressure level. This helps in the assessment of hypertension using PPG which is an inexpensive and handheld technique. The video is recorded using visible light which has a wavelength of about 400–700 nm. The red wavelength range in the visible light range is about 620–750 nm. The red wavelength of visible light which gets reflected from the blood gives the morphological information of PPG signal.

In Sec. 2, the materials and methods that are employed in this work are briefly explained. Reflectance mode that detects blood volume changes is used to measure the pulse rate using an Android smartphone. The video is recorded with the dual LED flash turned ON. The recorded video is processed using a MATLAB program to estimate the pulse rate and to extract the features of pulse wave from both normal and hypertensive patients. In Sec. 3, the selection of red channel in the frame is described; the resultant graphs obtained by applying specific functions and the confusion matrix for the features before and after the feature selection process are discussed. In Sec. 4, we compare the pulse rates measured using different methods. In Sec. 5, we conclude this work and the future extension of this work is described.

MATERIALS AND METHODS

Materials: Hardware

The Android smartphone used for this work is LETV LE MAX 2 and the model number is Le X821 which is having an OS of Android 6 and powered by a Snapdragon 820 quad-core 2.15-GHz processor. The features of LE MAX 2 include 21-megapixel (MP) primary camera on the rear and 8-MP camera on the front. It consists of a dual-LED, dual-tone flash with a separation distance of 2 cm. The camera records a video at 30 frames per second (fps) of 1080 pixels. Sony IMX230 Exmor RS is the image sensor model present in the camera. The characteristics of the sensor determine the quality of the camera. The sensor type employed here is CMOS (complementary metal–oxide–semiconductor) which also plays a major role in the quality. The video resolution, which is the information about maximum resolution available for shooting in video mode, is 3840×2160 pixels with 8.29 MP.

The type of file obtained from the color video recording is an MP4 file. Figure 1 shows the index finger that is placed on the camera thereby covering the LED. The dual-LED, dual-tone flash is turned on and the movie mode is activated. The video is recorded for at least 30 s. This works on the reflectance principle where the flash acts as an LED in pulse oximeter and recording camera acts as a detector. The video obtained from this method is transferred to a laptop for further processing using an USB cable.

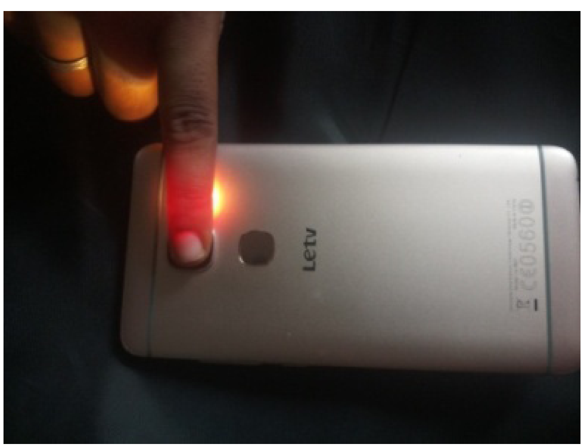

Fig. 1 Position of index finger over the video camera unit.

Pulse Rate Measurement

The program for processing the video that is recorded by using the Android smartphone is initiated by reading the video file using video reader function in MATLAB. The number of frames in the video, height and width of the video are displayed using the appropriate commands. This is continued by reading each frame from frame 1 to frame n by forming a "for" loop. The mean values of red, green and blue pixels from the frames are calculated and plotted by means of a graph. Next stage in the program is the filtering process which is done by using a "Butterworth band-pass" filter of order 8 and using the pass-band frequencies in the range of 0.8–7 Hz. On the data obtained from the filtering process, power spectral density (PSD) analysis is performed.

From the obtained data, red values from the frame resemble the actual PPG waveform. Thus, the red values are used for the calculation of pulse rate using an Android smartphone. Figure 2 shows the processes that are involved in this work.

Conversion of video signal to data. The recorded video signal is read in MATLAB by using VideoReader function available in MATLAB. This function helps in reading the video frame by frame; thereby all the frames are read, one at a time. ReadFrame function gives the corresponding frame with respect to a specific time until there are no more frames to read. NumberOfframe function gives the total number of frames present in the video file which helps in the further processing of data.

Feature Extraction

We extract 15 features from the mobile phone data of 70 normal subjects and 70 abnormal subjects using MATLAB program. The features that are extracted are peak interval, settling time, rise time, normalized PPG, first derivative, eigenvalue, peak width, peak prominence, peak-to-peak amplitude, second derivative, A amplitude, B amplitude, A/B ratio, B/A ratio and A width.

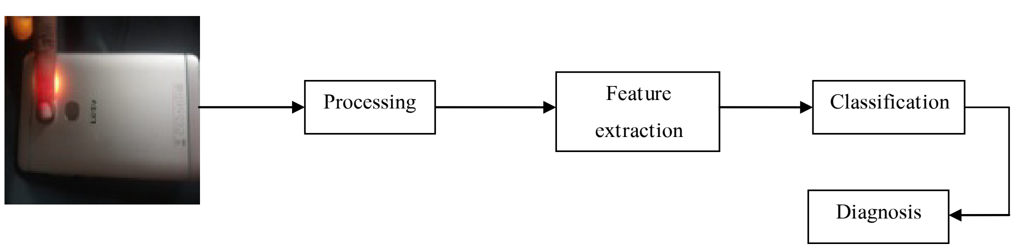

Fig. 2 Overall methodology.

The feature's peak interval is derived from the PPG signal by measuring the time interval between two consecutive peaks in the signal. The rise time of the PPG signal is determined by using the following formula:

$$\mathrm{RT} = t_p - t_e, \tag{1}$$

where RT denotes rise time, t_p is the peak time and t_e is the end time. The normalized form of PPG is obtained by using

$$S_n = \frac{S}{\sqrt{\frac{\sum_{i=1}^{N} |Si^2|}{N}}}, \tag{2}$$

where S_n is the normalized PPG, S is the original input signal and N is the length of the signal. The differentiation of original signal gives the first derivative feature and the differentiation of first derivative gives the second derivative feature. A amplitude can be determined by finding the amplitude of positive peak from the baseline. B amplitude gives the amplitude of negative peak from the baseline. B/A ratio is determined by using

$$\frac{B}{A}\ \text{ratio} = \frac{B\ \text{amplitude}}{A\ \text{amplitude}}. \tag{3}$$

Figure 3 shows the A and B amplitudes measured from the baseline in the second derivative of the PPG signal. A/B ratio is determined by using

$$\frac{A}{B}\ \text{ratio} = \frac{A\ \text{amplitude}}{B\ \text{amplitude}}. \tag{4}$$

Feature Selection

The feature selection process is done to identify the important features among all the extracted features from the original sample, which contribute most to the evaluation of hypertension. The feature selection process is performed by using the eigenvalues of the principal component analysis (PCA) method. The process of converting a set of correlated values into a set of linearly uncorrelated values by using an orthogonal transformation method is called principal component analysis. The uncorrelated values obtained from this method are called principal components which give the combination of original input values in a normalized linear pattern. The direction in which there is a highest degree of variation in the dataset can be determined. The highest variation is seen in the first principal component. The degree of variation in the succeeding component will be in an orthogonal manner to the preceding one. The principal component analysis is performed by using the eigendecomposition of covariance matrix. The eigenvalues obtained from this method show the degree of variation present in the data. The eigenvalue that is near or close to zero gives the principal components. These principal components give useful information whereas the components which have eigenvalues not close to zero are neglected. The features that are selected by the feature selection process of principal component analysis method are peak interval, settling time, rise time, normalized PPG, peak-to-peak amplitude, first derivative and second derivative. The selected features are then subjected to classification process using a neural network.

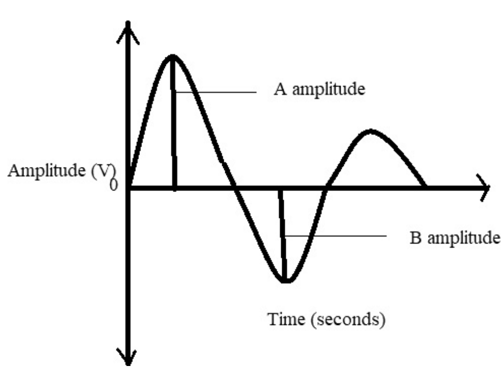

Fig. 3 Second derivative of the PPG signal.

The type of algorithm used to train the neural network is a back-propagation algorithm. In this algorithm, the weights of the network are fine-tuned depending on the error rate or loss function which is obtained from the previous iteration by using the gradient descent method. The updated weight which gives the lower error rate decides the solution for the neural network. The input and test data are loaded into the neural network tool and the number of neurons in the hidden layer is selected. This number can be changed if there is a lower accuracy after a training process. The neural network with input layer, hidden layer and output layer is trained and the confusion matrix is plotted to get the accuracy. If the optimal accuracy is not reached, the network is retrained. The accuracies of features before and after feature selection are determined.

RESULTS

The red channels in RGB signal with respective mean values are calculated in each frame. Figure 4 shows the mean values of red, green and blue pixels obtained from the recorded video. The resultant waveform obtained by calculating the mean of red channel resembles the photoplethysmographic waveform since blood absorbs most of the green and blue light from the LED due to its red-

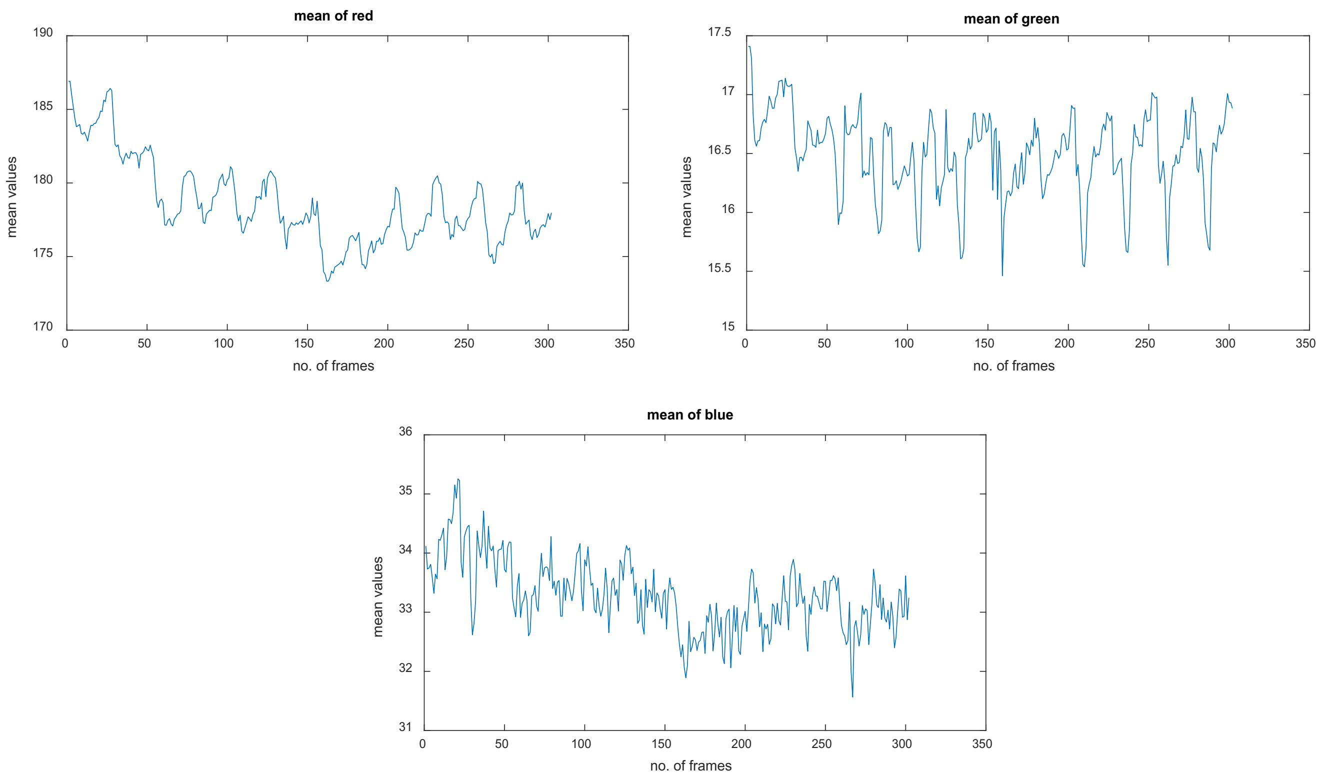

Fig. 4 Mean values of red, green and blue pixels from the frames.

colored nature and thereby reflecting the red light. The resultant graph is obtained while performing the filtering process by using the Butterworth band-pass filter of order 8 with a sampling frequency of 30 Hz. The lower cut-off frequency is 0.8 Hz and the upper cut-off frequency is 7 Hz. Figure 5 shows the red channel of the signal before and after the filtering process. Table 1 shows the comparison of the readings measured using pulse oximeter and smartphone for normal patients and hypertensive patients.

The resultant graph is obtained after performing the PSD analysis on each filtered channel of red, green and blue. The maximum peak intensity value of filtered red channel gives the pulse rate value when measured using a smartphone. The peak intensity values obtained from the other two channels are neglected because they show a greater variation in the pulse rate. Figure 6 shows the box plot for the feature of peak-to-peak amplitude.

Student's *t*-Test

Student's *t*-test value is determined to be around 0.6 which shows that the readings from the pulse oximeter and smartphone are similar for those values measured for normal and hypertensive patients.

Feature Extraction

Fifteen features are extracted from the mobile phone data for the normal and hypertensive subjects using the program. Table 2 shows the selected features after the feature selection process.

The extracted features, before performing the feature selection process, are classified using a neural network. The accuracy obtained from the classification process is only 75% which is very low. The specificity and sensitivity obtained here are 75.4% and 74.6%, respectively. After the feature selection process, the selected features from the recorded mobile data are classified using a neural network. The accuracy obtained by this process is 83.3%. The specificity and sensitivity obtained for selected features are 75% and 100%, respectively.

For validation purpose, a pulse sensor of KG011 connected to an Arduino UNO R3 microcontroller is used to record the pulse signal from the left index finger. The pulse signals recorded from 70 normal and 70 hypertensive patients undergo the feature extraction and feature selection processes. The accuracy obtained on performing classification of the extracted features is 82.9%. The specificity and sensitivity obtained are 80.3% and 85.9%, respectively.

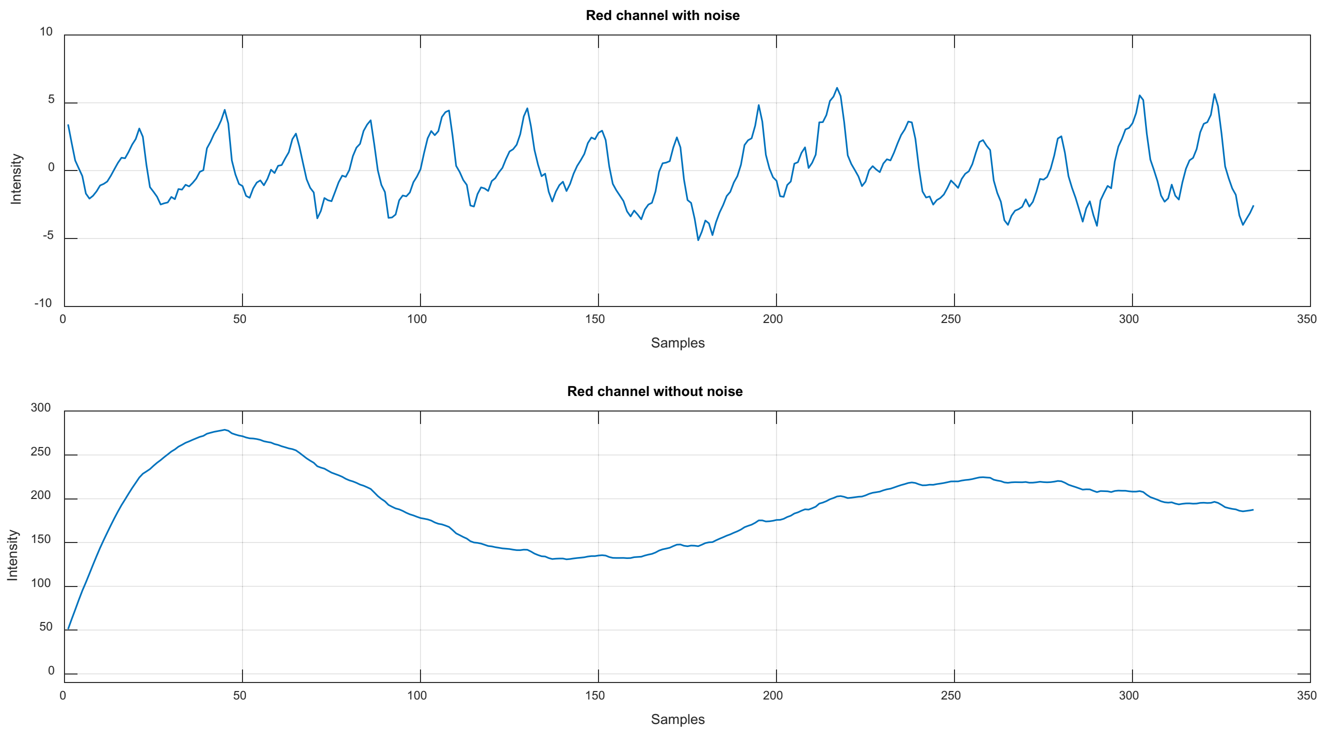

Fig. 5 Red channel with and without noise.

Table 1. Comparing the Pulse Rates Measured using Pulse Oximeter and Smartphone of Normal Subjects and Hypertensive Subjects.

	Normal Subjects		Hypertensive Subjects	
Subject	Measured using Pulse Oximeter (rate/min)	Measured using Smartphone (rate/min)	Measured using Pulse Oximeter (rate/min)	Measured using Smartphone (rate/min)
1	60	68	67	68
2	80	82	84	80
3	70	68	74	72
4	84	82	82	80
5	74	74	102	92
6	73	71	70	76
7	82	82	85	88
8	74	76	105	82
9	80	78	79	71
10	84	86	85	82

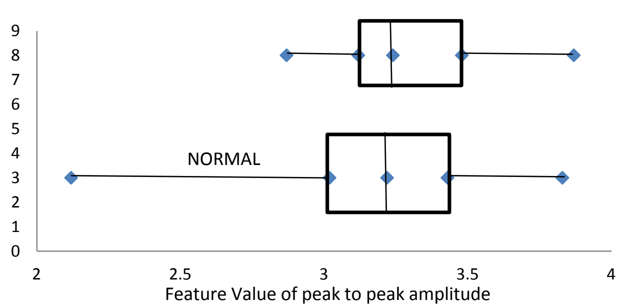

Fig. 6 Box plot for the peak-to-peak amplitude feature.

DISCUSSION

The pulse rate measured using the proposed method is compared with the one measured using a pulse oximeter, which shows the nearly similar readings of the pulse rate. The pulse rates are also measured from both the normal and hypertensive patients using the pulse oximeter and smartphone.

Liang *et al.* show the assessment of hypertension using photoplethysmography by using different types of feature selection processes.[1] The correlation between the

Table 2. Features Selected after Feature Selection from the Mobile Phone Data.

Feature	Normal Subjects (Mean ± Standard Deviation) ($N = 70$)	Hypertensive Subjects (Mean ± Standard Deviation) ($N = 70$)
Peak interval	0.14 ± 0.24	0.03 ± 0.17
Settling time	110 ± 255	10 ± 245
Normalized PPG	0.26 ± 0.93	0.66 ± 0.95
Rise time	1.54 ± 1.92	1.68 ± 1.97
Peak-to-peak amplitude	2.12 ± 3.4	2.87 ± 3.88
First derivative	0.1 ± 0.23	0.12 ± 0.22
Second derivative	0.05 ± 0.18	0.1 ± 0.2

BP levels and PPG features was established based on hypertension risk stratification approach. PPG feature of peak-to-peak amplitude correlates with the physiological phenomenon of systolic blood pressure. Greater the peak-to-peak amplitude, greater is the chance of hypertension due to greater systolic blood pressure.

Liang *et al.* explored the physiological changes that take place during different blood pressure levels depending on the arterial wave propagation theory.[7] The features of PPG show the condition of changes in the vascular tissue and volume of blood. Based on the BP level, PPG features provide information about the changes in the vascular stiffness and compliance and also vascular aging. The features of PPG signal that varies depending on the BP level give necessary information about the heart and the arteries.[13]

Jonathan and Leahy used the green channel of the visible light that is reflected from the index finger for photoplethysmographic imaging with a mobile phone that is operated using video mode.[8] Compared to this study, we performed the pulse rate estimation process over the red channel of the visible light which shows better morphological information of PPG signal that is obtained from the video recorded using the Android smartphone. Sukaphat *et al.* used the camera of Android smartphone that is equipped with the LED flashlight for recording the light intensity and concluded that the red channel in the RGB signals in each frame recorded for about 40 s using the smartphone returned the information of plethysmographic signal.[9] Compared to this study, our method requires only 30 s for determining the pulse rate from the video recorded using smartphone. The p-value obtained on performing the Student's t-test is 0.6 which shows that there is not much difference between the pulse rate readings measured using the conventional pulse oximeter and Android smartphone.

Elgendi described the potential information that are embedded in the waveform of PPG signal; he also further elucidated its applications that are beyond pulse oximetry and the heart-rate calculation and performed the analysis of PPG waveform, thereby describing its features.[10] Kurylyak *et al.* stated that the blood pressure can be estimated from the pulse duration of PPG signal using an artificial neural network and the analysis was done by using 15,000 heartbeats that were extracted from the intensive care database from which 21 parameters were extracted that can be used as an input data in artificial neural network.[11] Compared to these studies, we extracted 15 features from the PPG signal and by performing principal component analysis method, these 15 features are reduced to seven features depending on the eigenvalues of the PCA method. Also, our work shows improvement in the performance of the classifier when compared to the above-mentioned studies and got an accuracy of 83.3% when classifying the selected features from the video recorded using smartphone.

From the seven selected features, the peak interval feature that is extracted from the PPG signal of recoded video shows a similar accuracy for hypertensive patients as that mentioned in Ref. 10. The feature settling time gives higher value for normal patients than the hypertensive patients as mentioned in Ref. 10.

CONCLUSION AND FUTURE WORKS

Conclusion

This work has shown the possibility of measuring the pulse rate and evaluating hypertension using the Android smartphone's camera. It comprises the stages of data acquisition using the smartphone in video imaging mode and processing the recorded video in MATLAB and thereby extracting the features and classifying them to predict hypertension. The pulse rate readings measured using this technique are compared with those measured with the help of pulse oximeter and Student's t-test analysis is performed on the values measured using pulse oximeter and smartphone. The feature extraction and feature selection processes are performed on the pulse sensor data and mobile phone data. Therefore, the accuracy of prediction is determined.

Advantages and disadvantages of our proposed method. The pulse rate measurement method with greater accuracy is developed in this work. It gives the advantage of measuring our pulse rate using the handy device of smartphone which avoids the usage of bulky measuring devices. With the help of this method, we can measure the pulse rate at any emergency situation, within a short duration by simply recording a video. It acts immediately at difficult situation to find out the state of person as normal or hypertensive. The loss of data due to smartphone malfunction or loss of smartphone will be the disadvantage of this work.

Limitations of using smartphone in medical diagnosis. The limitations of using smartphone in medical diagnosis include data privacy and security that are a major concern. The data stored in memory will get lost or may be mishandled, if the smartphone is stolen or broken or lost. The inaccurate result will lead to false diagnosis. The prolonged use of smartphone will be harmful for our health due to the emanation of radiation from the device.

Future Works

The evaluation of hypertension using the video signal recorded from the smartphone can be used as a mobile application where the recording of video signal, processing of data and prediction of hypertension are done within a smartphone. This evaluation process can also be done by using computer interfaces such as Arduino, Raspberry Pi, etc.

REFERENCES

1. Liang Y, Chen Z, Ward R, Elgendi M, Hypertension assessment using photoplethysmography — A risk stratification approach, *J Clin Med* **8**(1):12, 2019.
2. Kobayashi H, Effect of measurement duration on accuracy of pulse counting, *Ergonomics* **56**:1940–1944, 2013.
3. Taha Z, Shirley L, Razman MAM, A review on non-invasive hypertension monitoring system by using photoplethysmography method, *Malay J Mov Health Exer* **6**:47–57, 2017.
4. Cheriyedath S, Photoplethysmography (PPG), www.news-medical.net/health/Photoplethysmography-(PPG).aspx, 2018.
5. Khandpur RS, in *Handbook of Biomedical Instrumentation*, 3rd edn., McGraw Hill Education (India) Private Limited, New Delhi, pp. 245–b, 2014.
6. Jahan E, Barua T, Salma U, An overview on heart rate monitoring and pulse oximeter system, *Int J Latest Res Sci Technol* **3**:148–152, 2014.
7. Liang Y, Chen Z, Ward R, Elgendi M, Hypertension assessment via ECG and PPG signals: An evaluation using MIMIC database, *Diagnostics* **8**(3):65, 2018.
8. Jonathan E, Leahy MJ, Cellular phone-based photoplethysmographic imaging, *J Biophotonics* **5**:293–296, 2010.
9. Sukaphat S, Nanthachaiporn S, Upphaccha K, Tantipatrakul P, Heart rate measurement on Android platform, *Proc 2016 13th Int Conf Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, 2016.
10. Elgendi M, On the analysis of fingertip photoplethysmogram signals, *Curr Cardiol Rev* **8**:14–25, 2012.
11. Kurylyak Y, Lamonaca F, Grimaldi D, A neural network-based method for continuous blood pressure estimation from a PPG signal, *Proc 2013 IEEE Int Instrumentation and Measurement Technology Conf*, Vol. 88, pp. 210, 2013.
12. Grimaldi D, Kurylyak Y, Lamonaca F Nastro A, Photoplethysmography detection by smartphone's videocamera, *Proc IEEE Int Conf Intelligent Data Acquisition and Advanced Computing Systems*, Vol. 9, pp. 88, 2016.
13. Kurylyak Y, Lamonaca F, Grimaldi D, Smartphone-based photoplethysmogram measurement, in Duro RJ, Lopez-Pena F (eds.), *Digital Image and Signal Processing for Measurement Systems*, River Publishers Series in Information Science and Technology, River Publishers, Aalborg, pp. 135–164, 2012.
14. World Health Organization, Global Health Observatory (GHO) Data: Raised blood pressure: Situation and trends, www.who.int/gho/ncd/risk_factors/blood_pressure_prevalence_text/en.html, 2013.