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Heart Rate Monitoring using Peak Detection in Photoplethysmography Signals of Fingertip Images Captured using Smartphone

Jean Effil N, Rajeswari R

Abstract*: Smartphone plays a major role in contributing towards preventive health care services, as they enable users to track by themselves, their diet and fitness regime. Monitoring vital signs particularly, heart rate regularly helps in early detection of heart related ailments. Given the present context, a smartphone is readily available with most of the population; hence it is much easy to monitor heart rate using the same. In this paper, a smartphone based application is presented which calculates the heart rate from the photoplethysmography (PPG) signals obtained from the fingertip images captured through the camera. Heart rate is calculated by counting the peaks that occur in the PPG signals in a particular duration. In order to detect the peaks, a peak detection algorithm proposed in [1] is used, as the algorithm helps in detecting peaks accurately without any pre-processing. The proposed technique is very simple as it calculates heart rate directly from time series PPG data without the need of converting to frequency domain data and can be employed in any smartphone to measure heart rate. In order to validate the proposed method, experiment was performed to calculate the heart rate of forty nine individuals and the obtained results were compared with heart rate readings measured using digital blood pressure (BP) monitor for those individuals. The heart rate obtained from proposed method is close to one that is obtained from digital blood pressure monitor with three percent discrepancy.

Index Terms*: Heart rate, Peak detection, Photoplethysmography, Smartphone

I. INTRODUCTION

Mobile technology and smartphones play a major role in everyday life, their importance and influence is growing day by day, and its necessity, would invariably, increase exponentially in the future [2]. Nowadays even basic smartphones are equipped with high end processors and numerous built-in sensors such as cameras with decent resolution, microphone, accelerometer, orientation sensor and light sensor [3]. Mobile operating systems provides excellent features and enables the developers to build exciting applications [4]. Utilizing smartphones for monitoring ones health is a trend that is increasing day by day, as not only is it readily available, but with a new breed of health conscious society, the need has become a necessity [5]. Heart rate (HR) is one of the vital health parameters, which is directly related to the well-being of cardiovascular system. Knowledge about the heart rate would assist in monitoring the fitness level and identify the evolving health problems, if any, in the human body. Electrocardiographs, pulse oximeters, digital blood pressure monitors, photoplethysmographic device are the devices available to measure heart rate. Nowadays, measuring heart rate using smartphones is also becoming popular [6], due to its readily available and non complicated nature.

One of the major advantages of using smartphones for heart rate monitoring is that it can be used in a non-invasive way to calculate the heart rate. Non-invasive monitoring has various advantages over invasive methods, as there is no need for injections, catheterization or administering anaesthesia. Moreover there is no need for hospitalization and there is no radiation involved hence there is no pain associated with non invasive methods. Many researchers have used the principle of photoplethysmography (PPG) to measure the heart rate using smartphones. The researchers have validated the smartphone PPG based method for calculating heart rate [7][10][15]. Daniel J Plews et al [8] have validated the method of measuring heart rate using PPG signals captured using smartphone to be a preferable one for athletes. When the heart beats, it pumps oxygen-rich blood to various organs and tissues of the body through arteries. Arteries are close to the skin such as fingertip or on earlobe , hence the change of blood volume in the finger artery can be detected easily. PPG is an optical technique used to measure the change in the quantity of blood in the skin surface by shining a light on the skin surface with a light source [7].

There are two techniques of measuring heart rate using smartphones: 1) Contact method and 2) Non contact method. Using contact method, pulse rate at the fingertip or toe tip or earlobe tip is measured by close contact of the body part with that of the camera lens. But in the non contact method, analysis of the subject's face is done by using the front camera. Heart beat causes changes in the skin color of the subject's face. This variation can be measured using the smartphone's camera and thus, the heart rate is measured [9][10][11]. Contact methods provide more accurate results when compared to non contact method [12][13].This paper proposes a peak detection based heart rate

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***** Correspondence Author
Jean Effil N*, Assistant Professor, Department of Computer Science, Manonmaniam Sundaranar University Constituent College of Arts and Scienece, Kadayanallur, Tirunelveli Dist, Tamilnadi, India
Rajeswari R, Associate Professor, Department of Computer Applications, Bharathisr University, Coimbatore, Tamilnadu, India

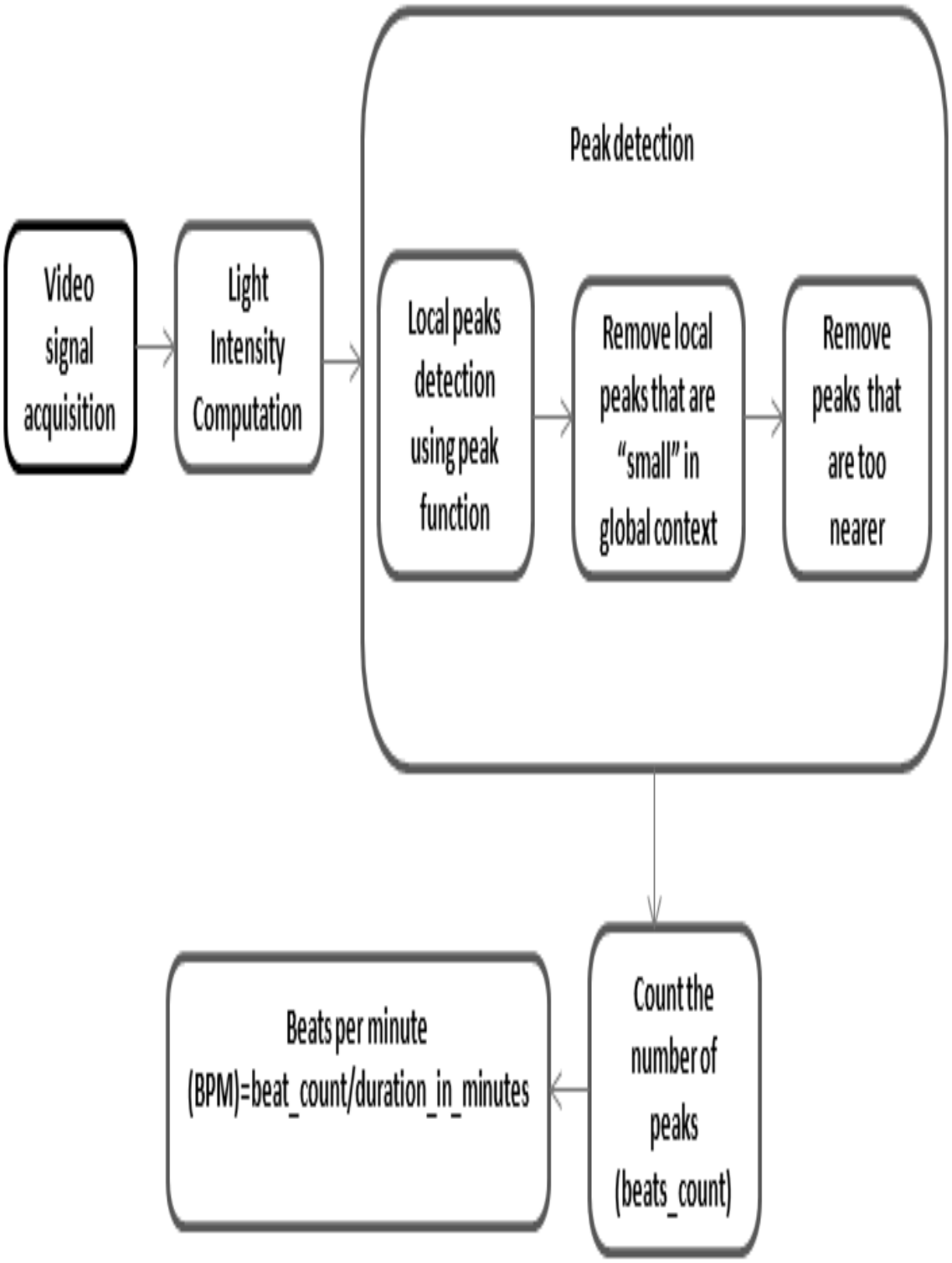

Fig.1: Block Diagram depicting the steps involved in heart rate calculation.

detection algorithm from PPG signals captured from fingertip using smartphone camera. The proposed method uses the peak detection algorithm proposed in [1], for effectively detecting the peaks from the extracted PPG signal. The main contributions of this research work are (1) the developed application is smartphone based, hence it can be used by people anywhere and at any time for monitoring heart rate (2) the developed heart rate detection algorithm uses peaks in the PPG signal, hence it is more accurate and (3) the proposed algorithm is very simple and does not require any preprocessing or smoothing operations.

The rest of this paper is organized as follows. Section 2 describes the underlying principles of measuring heart rate using smartphone and related research. Section 3 describes the proposed method for calculating heart rate using fingertip images captured from smartphones in detail. Section 4 explains the implementation of the proposed method and the experimental results obtained.

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It also provides the performance of the proposed method based on accuracy. Finally, Section 5 provides the conclusions and insights into future research areas.

II. UNDERLYING PRINCIPLES AND RELATED RESEARCH

Human heart rates can be measured using smart - mobile phones, by detecting color variations in the tip of the finger's skin. These color variations occur due to blood pulsating through the body at varied rates of speed and with different color variations during each blood circulation cycles. The skin color change is in accordance with the contraction and relaxation of heart, due to which, the blood volume in the finger's artery changes and relatively the skin color. The biology behind the color change is that, when the capillary is full of blood, it will allow passage of only a minimal amount of light, at the same time, when the blood retracts and the capillary is with less amount of blood, more light can pass through the tissues. This variation leads to varying intensities which in turn affects the color of the skin. The detection of change in blood color is made by irradiating and recording via video, the fingertip, with the aid of the smartphone's camera flash and the camera respectively, the video is captured for few seconds. The pixel information on each video frame can be separated into Red, Blue and Green components.

Average of all the pixel intensity values in the red plane or green plane or all the three planes(red, green and blue) is computed per video frame. The resultant average values and the timing of the corresponding video frames constitutes the input signals, this signal is used to measure heart rate. Many HR monitoring systems using smartphone have been developed based on similar technique [4][7][14][15]. However, the extracted signal is usually polluted with noise due to environment conditions, For example surrounding light intensity, movement of finger, pressure applied by the finger on the camera etc. The noise in the signal leads to the presence of fake peaks and suppresses the real peaks, which reduces the accuracy of heart rate calculation. To solve the noise problem, different filter types are used in heart rate measurement systems [14][15][16][17][18]. In some of the heart rate measurement systems, either the resultant signal is converted from time domain signal to frequency domain signal by using Fast Fourier Transform (FFT) algorithm [19] or a discrete wavelet transform is performed on the resultant signal [20].

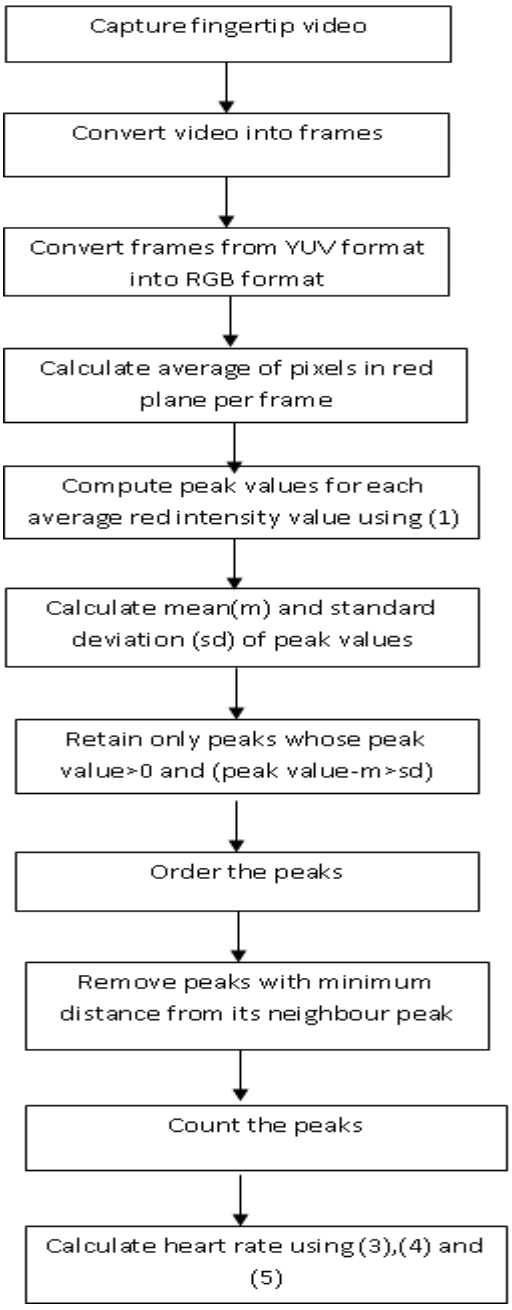

Fig 2 : Flowchart depicting the step by step process in heart rate calculation

In this paper, heart rate using the red component in acquired video frames via the smartphone is calculated based on peak detection. In particular, one of the peak detection algorithms proposed by Palshikar [1] is used in this work with the time series mean values of red component in video frames in order to accurately detect the peaks. This particular algorithm makes use of the peak detection based on the average of the (a) maximum value of the distance between a given location and its k left neighbours and (b) maximum value of the distance between a given location and its k right neighbours. This algorithm works directly on the raw data and no preprocessing such as filtering or smoothing is required and hence eliminates certain operations [1].

III. PROPOSED METHOD

The system uses the smartphone camera and its flash to determine the users heart rate in beats per minute. The overall system is developed in various phases viz., 1) video signal acquisition 2) light intensity computation 3) peak detection and 4) heart rate calculation. These phases are depicted in Fig 1. Flowchart depicting the step by step process in calculating heart rate is shown in Fig 2.

A. Video Signal Acquisition

Each volunteer was prepared to measure heart rate using digital blood pressure monitor and thereafter using the smartphone. Once the heart rate was obtained using the digital blood pressure monitor, the volunteer was asked to place

(a) HR measured using BP monitor. (b)capturing Fingertip video using smartphone camera

Fig.3 : The experimental setup

a fingertip on the smartphone camera lens with flash light turned on. The video of the fingertip was captured for 60 seconds. Fig 3 gives a snapshot of the experimental setup used in this work. The developed mobile app which is based on the proposed method switches on the flash so that the video can be captured very clearly. While the video is being captured the volunteer should not move his/ her hands and should be stable in one position.

B. Light Intensity Computation

Video of fingertip from the smartphone camera was recorded at a sampling rate of 30 frames/sec. The brightness of the skin over a period of 60 seconds was calculated by processing each frame captured. Images acquired are in YUV format, it was converted to RGB format.

Among the red, green and blue component in RGB format, red component was chosen for brightness calculation, since almost all the image energy is in the red plane and helps in calculating heart rate values which are similar to the actual values. Average of the brightness value of all pixels in the red plane was calculated per frame, which is given by

$$R_{avg}(F[T]) = \frac{\sum_{i=0}^{w.h}(P_i)}{(w.h)} \quad (1)$$

where w is the width of the frame, h is the height of the frame, F[T] is the image frame and P_i is the red intensity value of the i^{th} pixel in the frame which ranges from 0 to 255.

C. Peak Detection

The time series average red component values of the frames obtained from the previous step was used as the signal for detecting the peaks. Let R[T] = R_{avg1}, R_{avg2}, … R_{avgn} be the time-series red component data containing n values that were obtained from previous steps. Peak function for each value in the time series data R[T] was calculated based on the peak detection function described by Palshikar in [1]. The peak function indicates the significance of the height of the peaks. The peak function for i^{th} value, R_{avgi} can be expressed in (2),where the value of w was chosen as 4.

$$P(R_{avgi}) = \frac{\max(R_{avgi}-R_{avgi-1},R_{avgi}-R_{avgi-2},\ldots,R_{avgi}-R_{avgi-w})+\max(R_{avgi}-R_{avgi+1},R_{avgi}-R_{avgi+2},\ldots,R_{avgi}-R_{avgi+w})}{2} \quad (2)$$

Only the values R_{avgi} in the time series which satisfy the following condition were selected.

$P(R_{avgi}) > 0$ and $(P(R_{avgi}) - m) > sd$

where m and sd are the mean and standard deviation of all peak function values respectively. The peaks that are "too near" to each other were removed by executing the following steps:

1. The resultant peaks were ordered in terms of increasing index in R[T].
2. The peaks that are within distance w of each other were identified, and the smaller peak value among the two, was removed.

D. Heart Rate Calculation

The count of peaks obtained from the previous step was represented as beat-count. Duration of measurement in minutes is calculated using (3) and (4). Then the heart rate is calculated by dividing the beat-count by the signal duration in minutes using (5).

$$PS = \frac{N}{FPS} \quad (3)$$

$$PM = \frac{PS}{60} \quad (4)$$

$$HR = \frac{beat-count}{PM} \quad (5)$$

where, PS is the period of video capture in seconds, N is the length of the input signal, FPS is frame per second, PM is the period in minutes and HR is the heart rate.

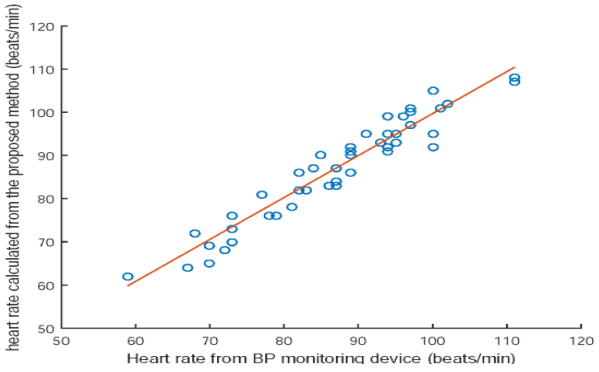

Fig. 4 : Comparison of HR reading measured using digital blood pressure monitor with HR obtained from proposed method using fingertip input from mobile camera.

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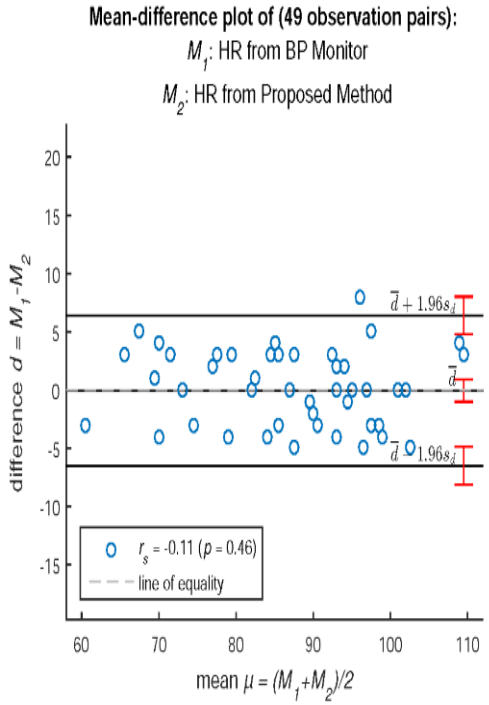

Fig. 5 : Bland-Altman technique used to show the difference between the actual HR value and the HR value obtained from proposed method.

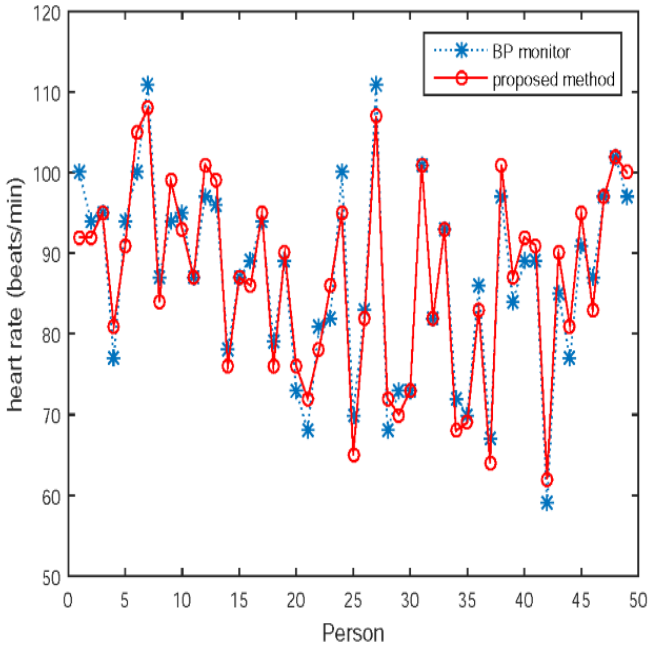

Fig.6 : Heart rate readings from proposed method and BP monitor using line graph.

Table 1 Single factor Anova test performed on two groups of data, HR obtained from BP monitor and HR obtained from proposed method.

Source of Variation	Sum of Squares	Mean Square	F	P-value	F crit
Between Groups	0.36	0.36	0.0026	0.9595	3.9381

IV. RESULTS AND DISCUSSION

The experiment was conducted for 49 volunteers, both male and female between the age range of 13 to 65. The people who participated in the experiment were the residents of Sadayampalayam village in Namakkal district. The digital blood pressure monitor was used for comparing the results obtained from the proposed method. An Android based smartphone was used for capturing the fingertip video. For each volunteer, the video of fingertip of left hand was recorded for 60 seconds. The video captured from fingertip was given as input to the proposed method. The results obtained from the proposed method were compared with HR values obtained from the digital blood pressure monitor. The scatter plot of heart rate values obtained from BP monitor and the proposed method is shown in Fig 4. From the scatter plot, it is apparent that the actual result and the result from the proposed method are comparable as the plotted points are tightly scattered about the line of equality. Also comparison using Bland Altman technique [21] was performed and the result is shown in Fig 5. In the Bland Altman plot, mean between actual value and one calculated using proposed method is plotted against the x axis and the difference between the two results are plotted against the y axis.

The plots clearly depict the accuracy rate of the proposed method and the overall results look acceptable. Line graph in Fig 6 was drawn that shows the coincidence of HR values obtained from BP monitor and the proposed method. The ERROR is calculated from the formula.

$$ERROR = \frac{ActualHR - HR\,from\,Proposed\,Method}{ActualHR} \quad (6)$$

The error observed was 0.030. Hence, the heart rate obtained from our experiment is close to one that is obtained from digital blood pressure monitor with 0.030 discrepancy.

ANOVA test with the significant level(α) of 0.05 was performed on two groups of data, the heart rate readings obtained from proposed method and that from BP monitor. The results are shown in Table 1. The results show that P-value > α and F-statistics less then critical value, hence there is no significant difference between the HR measures obtained from proposed method and that from the BP monitor.

V. CONCLUSION

In this paper, a smartphone based application that uses the variation of skin color observed in sequence of fingertip images along with a peak detection algorithm proposed in [1] to calculate heart rate is introduced . The computation of heart rate directly from raw PPG data without using any preprocessing techniques such as smoothing or filtering is elaborately discussed.

Finally, the validation of the proposed method performed using different techniques has been presented and the results demonstrate that there is no significant difference between heart rate calculated from proposed method and heart rate reading observed in BP monitor. By extracting area of interest from fingertip images and then applying the proposed algorithm would lead to better results which will be incorporated in the future work

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AUTHORS PROFILE

N.Jean Effil received the Master's degree in Computer Applications from Fatima College(Autonomous), Madurai, India, in 2003, M.Phil. degree from Periyar University, Salem, India, in 2007 and Master's degree in Computer Science and Engineering from Sathyabama University, Chennai, India, in 2011. She is currently working as an Assistant Professor, Department of Computer Science, Manonmaniam Sundaranar University Constituent College of Arts and Science, Kadayanallur, Tirunelveli Dist., India. She has 12 years of experience in teaching. Her research interests include signal processing, medical image processing and mobile health care applications.

R. Rajeswari completed her MCA in 2003 from Madurai Kamaraj University, Madurai, India and Ph.D. in Computer Science in 2012 from Bharathiar University, Coimbatore, India. She is working as Associate Professor in the Department of Computer Applications, Bharathiar University, Coimbatore, India since 2005. She has 15 years of experience in teaching/ research. Her main research interests include medical image processing, video processing and soft computing.