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Heart Rate Measurement Using Facial Videos

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Abstract

Heart rate is one of the major predisposing factors for cardiovascular diseases. Standard methods for measuring heart rate are Electrocardiogram and Pulse oximeter sensors. However, Electrocardiogram requires skin-contact using gel patches that can cause irritation to the patients. Pulse oximeter sensors, when attached to fingertips or earlobes for long time durations, can also cause pain. Therefore, this paper presents an innovative heart rate monitoring methodology that measures person's heart rate using their facial image. Videos captured using the camera, were separated into Red, Green and Blue (RGB) color channels which, were then converted to the Hue, Saturation and Intensity (HSI) color model. Cheeks were selected as the region of interest to which Brightness Preserving Bi- histogram technique (BBHE) was applied. Application of Principal component analysis (PCA) on the three color channels extracted new principal components. Proposed algorithm measured heart rate from the region of interest and through experimentation, it was found that the 3rd principal component having success rate of 84% is the most effective signal for the heart rate measurement, followed by the 2nd principal component having success rate of 80%.

Keywords: Heart rate, Facial image, BBHE, PCA, Biomedical signal processing.

I. INTRODUCTION

Heart rate is a crucial factor for the diagnosis of heart diseases and one of the dominant parameters for cardiovascular diseases. Heart rate is defined as the rate at which heart contracts per minute. It is a vital physiological signal measured in the human body that reflects the physical and mental state. Heart rate variability is a measure of variations between each heartbeat that indicates the effects of stress on a person's body. With the rise of unhealthy eating habits and sedentary lifestyles across the world, mortality rates due to cardiovascular diseases (CVDs), stroke, septic shock, coronary heart diseases (CHDs) are rapidly increasing. Ischemic heart disease and stroke are the two major cardiovascular diseases responsible for 80% deaths in India [1]. Therefore, the adaption of a healthy lifestyle with the regular examination of heart rate is essential to keep these diseases at bay.

Standard medical techniques to monitor heart rate are Electrocardiogram (ECG) and Pulse Oximeter sensors [2]. These conventional methods provide accurate heart rate but the application of these devices can cause damage to elderly skin. Moreover, wearing these devices for long time duration can cause extreme discomfort to patients. Also, it cannot be used on neonates. Due to the complex hardware, usage of these machines at home can become complicated without any specialist's supervision. Therefore, interest is growing to measure heart rate without any contact between patients skin with the hardware so that it can be measured without any discomfort.

Photoplethysmography (PPG) is a technique that measures the changes in blood volume caused by scattering of light due to the flow of blood in the body parts. Because of its non-contact nature of sensing, PPG is currently gaining popularity. Face images captured by using the camera carries information about minute color changes in the skin caused due to the beating of heart, blinking of eyes and other physiological activities occurring in the body that generates pulse wave signals which cannot be seen by the naked eye. For computation of these crucial physiological signals from facial videos, researchers have designed approaches [3]. Pho et al. presented a methodology which measured heart rate by separating red, green and blue color channels from a facial video and employed independent component analysis (ICA) on them [4].Kwon et al. implemented Fast Fourier Transformation (FFT) on normalized red, green, blue channels and the heart rate was extracted from ICA by analysing color channels which proved that although all color channels contain PPG signals, but the green channel possesses the strongest one. But the results got worse due to the application of ICA [5]. Garala A. et al. designed an approach that extracted the spectrum of the Red, Green and Blue color channels using Discrete Fourier Transform (DFT) to which theorem of z-score was applied for data standardization [6]. Experimental results validated that red channel was the most effective color channel, closely followed by blue channel. Lueangwattana C. et al employed PCA to the means of R, G, B channels. Simultaneously, the RGB color model was converted into HSI color model and the mean of hue channel was computed. Fast Fourier Transformation followed by the bandpass filter and z-score theorem was applied to PCA and hue channel for heart rate measurement [7].

This study focuses on an advanced technique of histogram equalization known as Brightness Preserving Bi-Histogram Equalization (BBHE). It is applied on facial videos to overcome brightness issues. Through its application, video's mean brightness can be successfully retained and its contrast can be enhanced in low or varying light conditions.

II. METHODS

A. Brightness Preserving Bi-Histogram Equalisation (BBHE)

BBHE is an advanced technique of histogram equalization (Yeong- Taeng Kim) [8] also known as Bi -histogram equalisation. It deals with the mean- shift problem faced by histogram equalisation and is used to retain the mean brightness of an image meanwhile increasing the contrast of it. In BBHE, histogram of an input image is splitted on the basis of mean value into two sub- images histograms named as upper and lower histograms. The Range of histogram lies from 0 to 255(L-1) in which lower histogram ranges from the first gray level to the mean value and upper histogram ranges from second mean value to the last gray value. Further, the upper and lower histograms are equalised using probability density function (PDF) and cumulative distribution function (CDF).

Let I_m denotes the mean of the image I and suppose that I_m $\{I_0, I_1\ldots, I_L\text{-}1\}$ [9]. On the basis of mean, the input image is partitioned into two sub-images I_L and I_U as

$$\mathrm{I} = \mathrm{I}_L \cup \mathrm{I}_U$$

$$I_L = \{I\ (a,\mathrm{b})\mathrm{I}\ (a,b)\ \le \mathrm{I}_m, \forall\ \mathrm{I}(a,b) \in I\} \tag{1}$$

$$I_U = \{I\ (a,\mathrm{b})\mathrm{I}\ (a,b) > \mathrm{I}_m, \forall\ \mathrm{I}(a,b) \in I\} \tag{2}$$

Where sub-image I_L contains values $\{I_0, I_1\ldots \mathrm{I}_m\}$ and the other sub image I_U contains values $\{\mathrm{I}_m+1, \mathrm{I}_m+2\ldots I_L\text{-}1\}$.

Probability density functions of the sub-images I_L and I_U as

$$p_L(I_t) = \frac{n^t{}_L}{n_L} \tag{3}$$

Where t = 0, 1… m

$$p_U = (I_t) \ = \frac{n^t_U}{n_U} \tag{4}$$

Where t = m+1, m+2…, L-1. In above equations n^t_L and n^t_U denotes the numbers of Ik in I_L and I_U, n_L and n_U are the total number of samples in I_L and I_U respectively.

The cumulative density functions For I_L and I_U are then defined as respectively.

$$C_L(I) = \sum_{j=0}^{m} p_L(I_j) \tag{5}$$

$$C_U(I) = \sum_{j=m+1}^{k} p_U(I_j) \tag{6}$$

T_L and T_U defines the transfer functions utilizing the cumulative density functions as

$$T_L(I_k) = I_0 + (I_m - I_0)C_L(I_K) \tag{7}$$

$$T_U(I_K) = I_{m+1} + (I_{L-1} - I_{m+1})C_U(I_K) \tag{8}$$

Based on above transform functions, sub images I_L and I_U are equalized independently.

$$Z \ = \ \{ \ Z(a,b) \ \} \tag{9}$$

$$T_L(I_L) \cup \mathrm{T}_U(I_U) \tag{10}$$

Z is expressed as the output of BBHE having independently equalized sub-images.

$$T_L(I_L) = \{T_L\left(I(a,b)\right) \mid \forall I\left(a,\mathrm{b}\right) \in \ \mathrm{T}_L\} \tag{11}$$

$$T_U(I_U) = \{T_U(I(a,b)) \mid \forall I(a,b) \in \ \mathrm{T}_U\} \tag{12}$$

It is to be observed that $T_L(I_L)$ equalizes the sub-image I_L ranges over (I0, I_m) and $\mathrm{T}_U(I_U)$ equalizes the sub-image I_U ranges over (I_{m+1}, I_{L-1}).As a result, the input image I is equalized over the entire range (I_{m+1} , X_{L-1}) with the constraint that samples having values less than input mean are mapped to (I0, I_m) whereas the samples having values greater than mean are mapped to (I_{m+1} ,I_{L-1}). Then the histogram of the resultant image can be expressed as

$$g(a,\ b) = T\left(I(a,\ b)\right) \tag{13}$$

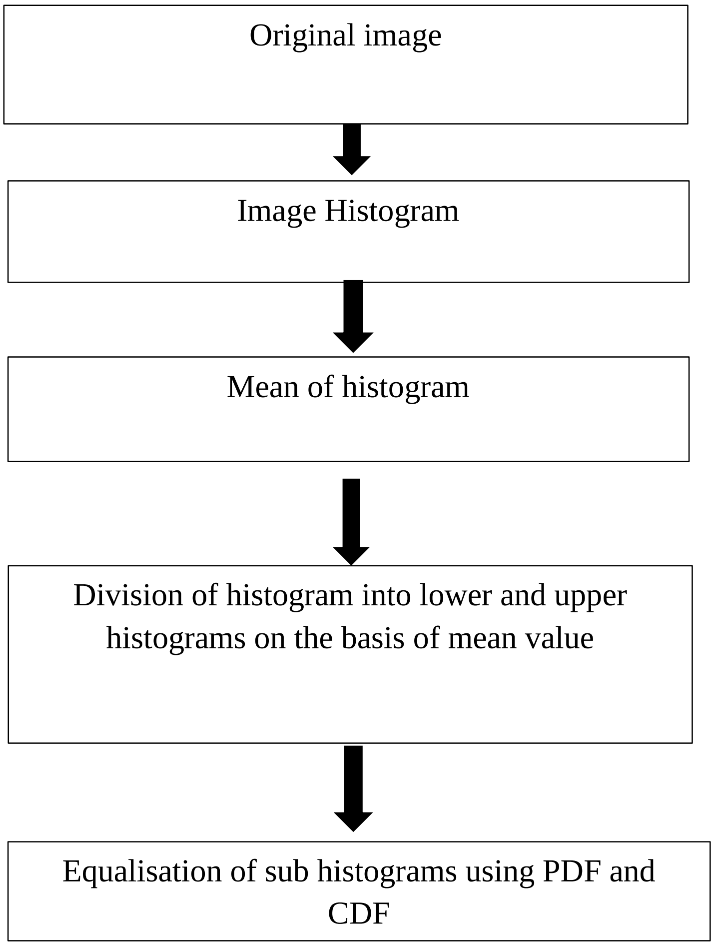


Fig.1: BBHE Flowchart.

B. Signal Extraction

From the recorded video, the region of interest was separated into Red, Green and blue components which were then converted into HSI color model. Finally the means of signals red (R), green (G), blue (B) and hue (H) was taken.

C. Principal component analysis

PCA is a technique which fetches out strong patterns from the signals to reduce data dimension. It is used to find out new principal axis where all the data is widely spread. It uses the orthogonal transformation that converts correlated variables into a small number of uncorrelated variables known as principal components. Each principal component carries new information regarding the data set. Components are arranged such that initially few components justify for maximum variability. It is performed on a particular set of data rather than on whole data set.

If A is a covariance matrix having variance $\mathbf{S^2}$ and covariance **S.** Then eigenvalue $\boldsymbol{\lambda}$

can be obtained by subtracting eigenvalue from covariance matrix and taking the determinant of it.

Here I is the identity matrix in equation (14).

$$\text{Det}\ (A-\lambda I) = 0 \tag{14}$$

Corresponding eigenvectors **u** can be calculated as

$$Au = \lambda u \tag{15}$$

The first eigenvector **u** will be derived from the largest eigenvalue **λ** and other lower eigenvectors will be derived from other lower eigenvalues that will give principal axis respectively.

The new data set **Y** is defined as the input data that is projected onto the eigenvectors. It is the product of the transpose of eigenvector **u** and the random input data **X**.

$$Y = u' X \tag{16}$$

The data **Y** is also known as principal component.

D. HSI color model

HSI (Hue, Saturation, and Intensity) is a color model based on the apprehension of color recognition by the observer. Hue component determines the dominant wavelength that observer can see which is in the arrangement of an angle between [0,360] degrees where 0^0 specifies red color, 120^0 specifies green color, 240^0 specifies blue color, 60^0 specifies yellow color and 300^0 specifies magenta color. Saturation indicates the quantity of white light (or gray) that is merged with the hue. The Range of saturation is [0, 1]. Intensity defines the brightness of color [7]. Colors in HSI are given as

$$H = \cos^{-1}\theta\{\frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)]^2+(R-B)(G-B)]^{1/2}}\} \tag{17}$$

$$S = 1-\frac{3}{(R+G+B)}\min(R,G,B) \tag{18}$$

$$I = \frac{1}{3}(R+G+B) \tag{19}$$

E. Participants

Facial Videos were recorded from fifteen sound and healthy male volunteers (23-27 years of age) in the day time. Volunteers were asked to sit 1 meter away from the camera. They were told to sit in a comfortable posture with spontaneous breathing. At the same time, they were asked to wear Biopac chest belt type heart rate monitor. The videos were recorded for a time duration of 20 seconds from all the volunteers.

F. Experimental Setup

The experiment was designed to be conducted indoors with fluorescent light bulbs. Camera was used for the recording of videos. Videos were recorded in 24-bit(3channels × 8 bits/channel) RGB color with 640 ×424 pixel resolution. Videos were saved in MOV file format. From the volunteer's recordings, cheeks were selected for analysis.

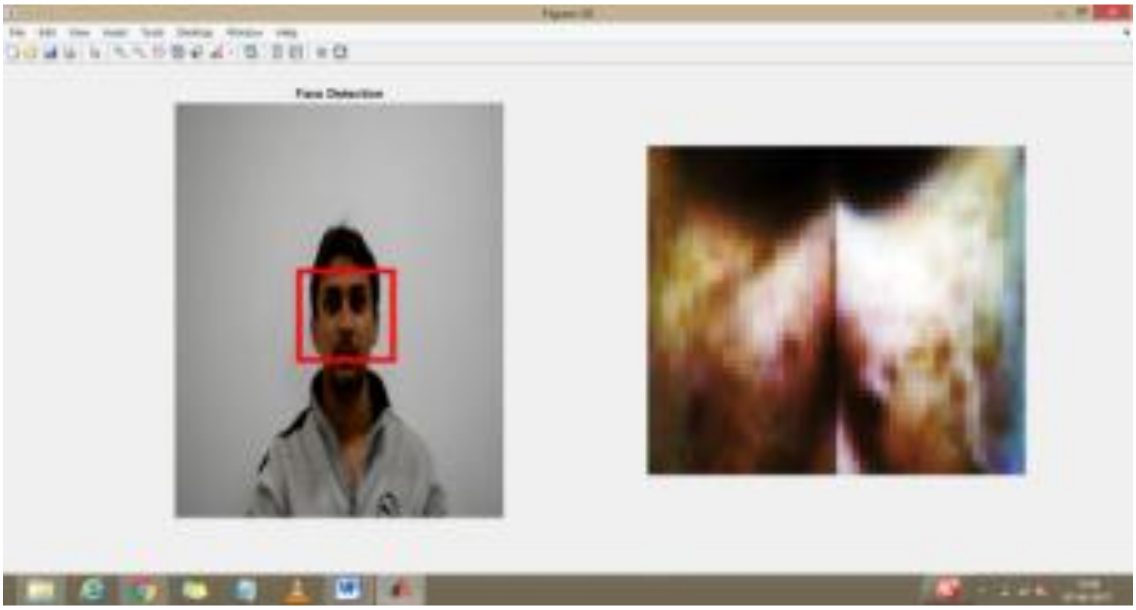


Fig.2: Volunteer face and cheek selection.

G. Algorithms

Fig.3 illustrates the flow chart of the proposed algorithm. Firstly, volunteer's videos were imported in Matlab.

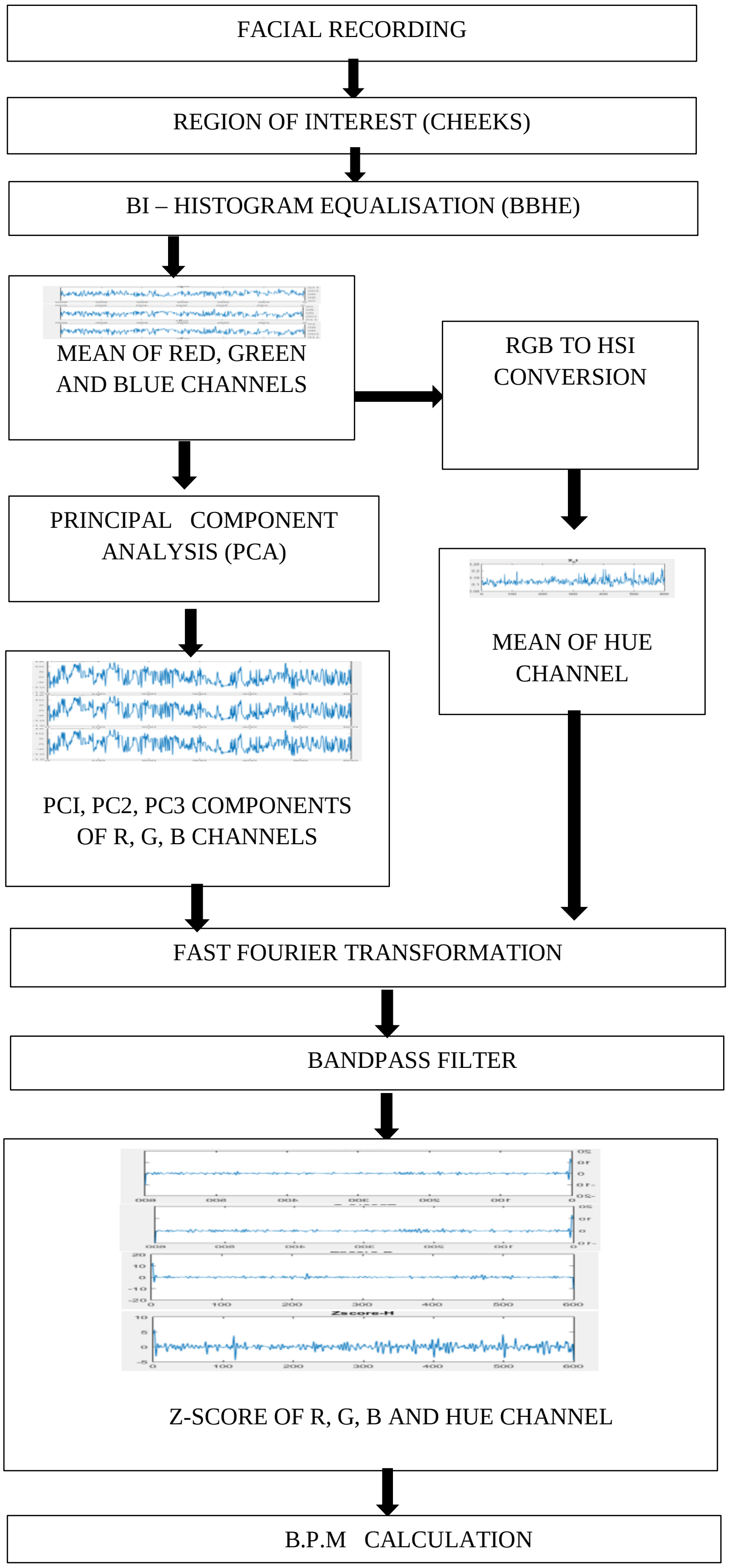


Fig.3: Flowchart of proposed algorithm.

Cheeks were taken as the region of interest (ROI) to which Bi histogram (BBHE) technique was applied. Means of red, green and blue channels of the cheeks were evaluated. Principal component analysis was employed on them. Simultaneously, Red, Green and Blue channels were converted into HSI color model and mean of hue channel was also computed. Further, Fast Fourier Transformation was applied to extract the domineering frequencies that were carried by the four channels. To the Fast Fourier Frequency spectrums, band pass filter was applied which diminished very low and very high frequencies but kept a band of middle ranged frequencies. The Bandpass filter's width ranged from 14^{th} to 41^{st} spectrums equivalent to 39 to 120 BPM. Z-score theorem was applied to the bandpass filter in order to standardize the data and the dominating spectrum is evaluated as

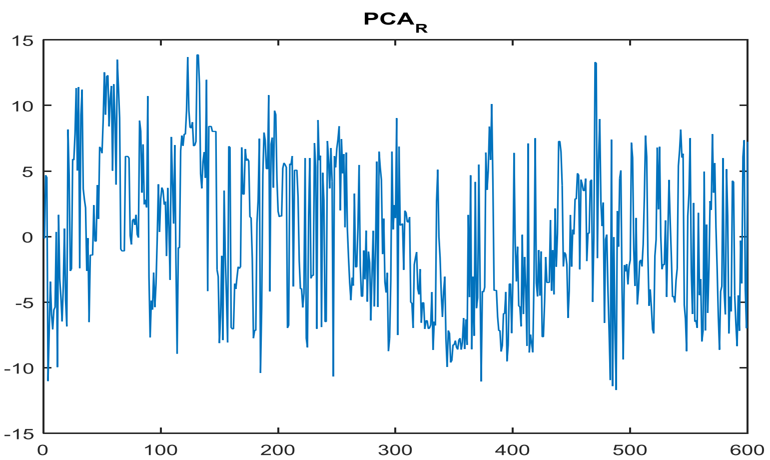
$$\mathbf{z} = \left(\frac{x-\mu}{\sigma}\right) \tag{20}$$

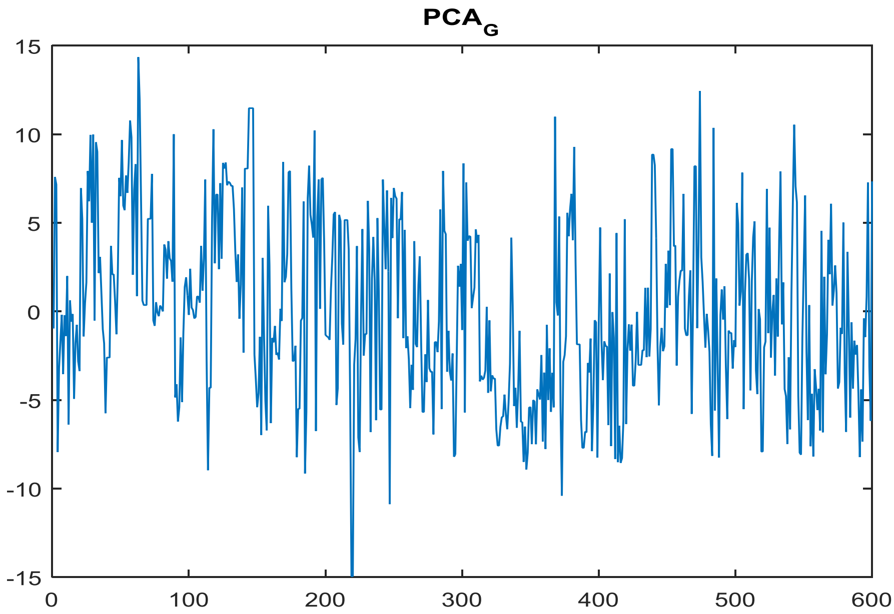
Where z is z- score, **μ** is **mean** and **ϑ** is **variation**.

III. RESULTS AND DISCUSSION

Videos of the volunteers taken for this study were analysed in MATLAB. Face detection algorithm was applied and resultant heart rate was compared to the Biopac chest strap belt type heart rate monitor. For each signal, z- score was calculated through which highest z-score index value was attained. Finally, heart rate was calculated by multiplying the highest index value with the ratio of time taken to record video (20 seconds) per one minute (60 seconds).

The plot of principal component red, green and blue channels and the plots of z- score hue (H), red (R), green (G), blue (B), PCA 1, PCA 2 and PCA components are shown in Fig. 4 and 5.





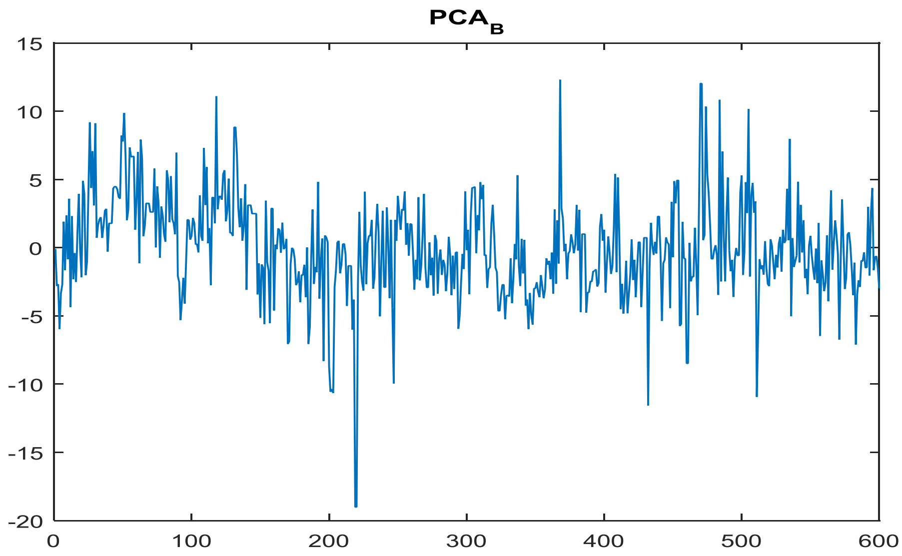


Fig.4 Principal Components of Red, Green and Blue Channel.

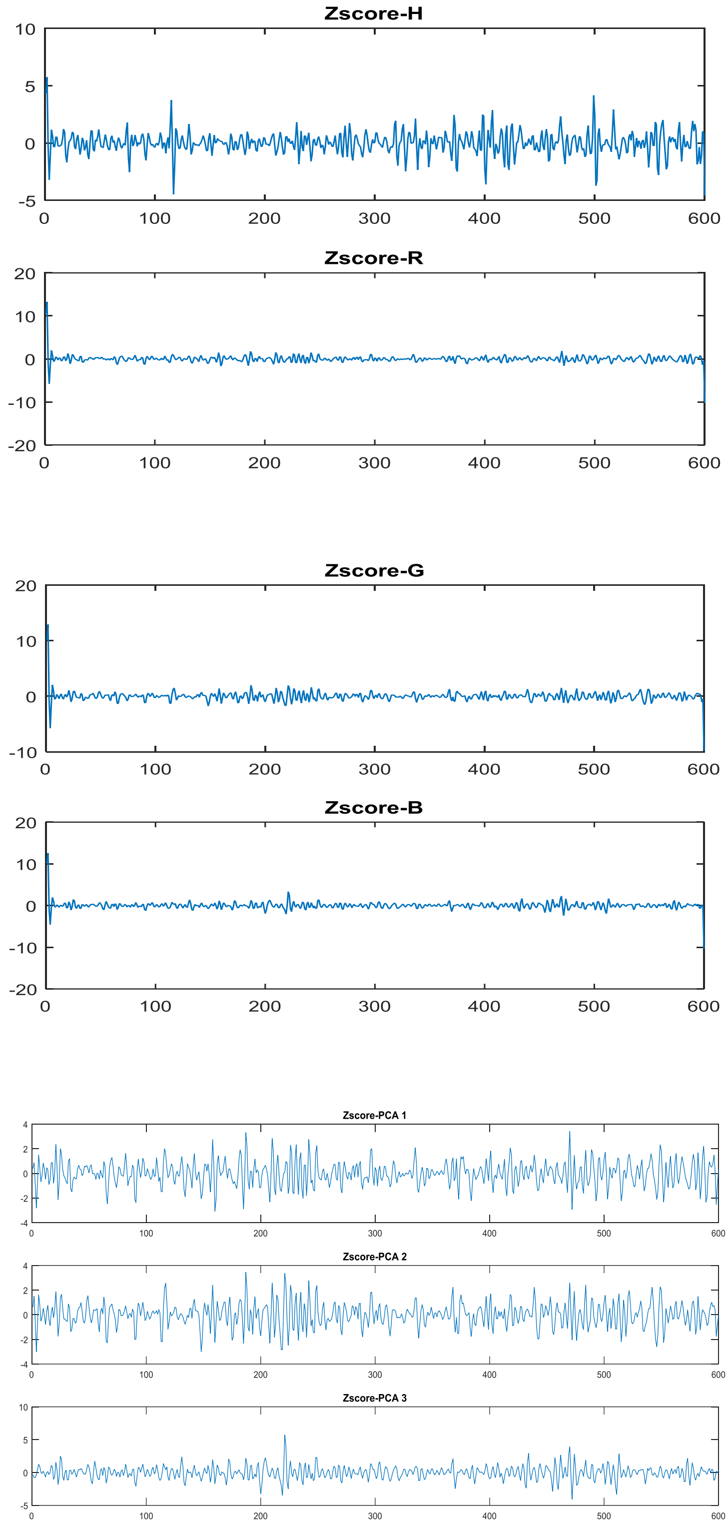


Fig. 5 Z-score of Hue (H), Red (R), Green (G), Blue(B), PCA 1, PCA 2, PCA 3.

Table I. COMPARISON OF HUE CHANNEL AND PRINCIPAL COMPONENTS OF RGB COLOR CHANNEL

CHANNEL	**HUE**	**PC1**	**PC2**	**PC3**
Success Rate	79.909	75.6199	80.3038	84.0659
Correlation	0.96482	0.96821	0.96775	0.96754
Z-score mean	0.95662	1.9963	2.0766	2.1441

Table I. shows results of Success rate, Correlation and Z-score mean for principal components of RGB color channels and hue channel. Correlation shows the difference between algorithm results and reference B.P.M. Z-score mean indicates the reliability of excellent spectrum among each signal.

Table II. represents the detailed results of all the color channels. Principal components of red, green and blue color channels were evaluated. Component having heart rate exactly or closely related to the reference heart rate is selected as final BPM. Results showed that 3rd principal component of the blue channel is the most effective signal having success rate of 84% followed by 2nd principal component of the green channel having success rate of 80%.

Table II. HEART RATE VALUES OF 15 VOLUNTEERS FROM ALL THE COLOR CHANNELS.

VOLUNTEERS	GROUND TRUTH(BPM)	HUE	RED	GREEN	BLUE	PC1	PC2	PC3	Error	FINAL BPM
1	75	51	63	63	75	63	63	75	0	75(PC3)
2	83.6	60	93	90	90	93	90	90	6.4	90 (PC3)
3	82	72	78	78	78	78	78	78	4	78(PC3)
4	86.0667	75	63	120	120	63	120	120	11.0666	75(HUE)

5	91	102	81	93	117	81	93	117	2	93(PC2)
6	81	51	72	75	75	72	75	75	6	75(PC3)
7	78	48	87	87	87	87	87	87	9	87(PC3)
8	67	84	123	63	63	123	63	63	4	63(PC3)
9	74	51	102	102	75	102	102	75	1	75(PC3)
10	76	57	78	78	93	78	78	93	2	78(PC2)
11	74.75	63	111	51	111	111	51	111	11.75	63(HUE)
12	85	78	84	45	105	84	45	105	1	84(PC1)
13	80.5369	96	96	54	72	96	54	72	8.5369	72(PC3)
14	74.7664	75	114	90	90	114	90	90	0.2336	75(HUE)
15	86.8936	90	111	111	84	111	111	84	2.8936	84(PC3)

The average error rate achieved by our system is of 4.658%. Hence, Principal component of blue channel (PC3) is the final component selected whose results are shown in Table III.

Table III. RESULTS OF FINAL B.P.M (PC3).

Success Rate(PC3)	84.0659%
	(9 of 15)
Correlation	0.56385
Z- Score mean	2.1441

IV. CONCLUSION

In this paper, a methodology for measuring heart rate using person's facial image was implemented. Feasibility of the task was tested using Red, Green, Blue, Hue channels and 1st, 2nd, 3rd principal components of R,G,B channels from the video sequences. From experimental results, it was found that blue channel contributed mainly to the 3rd principal component. Heart rate measurement reliability can be computed by the Z-Score of FFT spectrums. Results showed that PC3 component of blue channel is the most effective signal followed by PC2 component of green channel. Also proposed method is a cost effective, non–contact heart rate measurement which is reliable and comfortable for users. Through the experiment it was found that quality of the video matters. For highly compressed videos, heart rate measurement will be inaccurate. On the basis of Z-score values, signals behaved differently under varying or low light conditions. Thus, BBHE technique was applied to minimize low light effect. Therefore, the proposed method is reliable with 84% efficiency. As future work, we are planning to conduct study on more volunteers.

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BIOGRAPHICAL SKETCH

Garima Uppal is a current student at PEC University of Technology, pursuing her Master of Technology in Industrial Design. She was born in Naya Nangal, Punjab and did her schooling at Captain Amol Kalia Fert. Model Sen. Sec. School, Naya Nangal. She pursued her Bachelor's Degree in Computer Science Engineering at Chitkara University, located in Himachal Pradesh in 2015. Upon completion of her Master's degree in August 2017, Garima hopes to make her career in teaching profession.

She has participated in many activities. In her bachelor's degree, she was a member of IETE club. She also joined happy club where the main aim was to help poor and needy people. She has worked on projects that include Php (Music and dance academy website, Govt. Jobs info website), Core java project (Car parking management system). Currently, she is working on her thesis topic: "Heart rate measurement using facial videos".