

# Statistical Features Based Decision for Placement of Optical Sensor on Prefrontal Lobe for the Acquisition of Cranial PPG Signal in Emotion Analysis

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In this work, the effect of sensor placement on the prefrontal lobe for emotion classification is analyzed with the objective of achieving maximum classification accuracy. Photoplethysmography (PPG) signals are acquired from the prefrontal region by positioning sensors at the left, central, and right prefrontal locations. Prefrontal PPG signals are recorded for two emotional states, namely *happy*, *sad*. A six-level wavelet decomposition is performed on the acquired PPG signals to obtain approximation (A6) and detail (D6) coefficients. Statistical features such as mean, variance, energy, and entropy are extracted from the wavelet-decomposed signals. The extracted features from the original PPG signal, as well as from the A6 and D6 components, effectively discriminate among different emotional states. The results demonstrate significant variations in statistical feature values across emotions. Furthermore, box plot analysis reveals that the differentiation between *happy* and *sad* emotions is more pronounced in the central prefrontal PPG signals compared to the left and right prefrontal signals. Consequently, features derived from the central prefrontal PPG signal are identified as more suitable for emotion classification. Central Prefrontal CPPG: Difference in mean between Happy and Sad is 35.58 and difference in variance between Happy and Sad 2924.66 for central A<sub>6</sub> scale. For central D<sub>6</sub> scale difference in variance between Happy and Sad is 1.14E+006. Difference in energy between Happy and Sad is 7176 and difference in entropy between Happy and Sad is 8.8E+006 for central A<sub>6</sub> scale. For central D6 scale difference in energy between happy and sad 4422.59 and difference in entropy between Happy and Sad is 1.14E+006.

**Keywords:** Classification, Emotions, Prefrontal Photoplethysmogram, Statistical Features, Wavelet.

Human emotions can be identified through the analysis of physiological signals. Emotion recognition research has shown significant advancement and is broadly categorized into two approaches first based on multichannel physiological signals and second based on multimodal signals. Feature extraction and

dimensionality reduction play a crucial role in improving the performance of emotion recognition systems.

Electroencephalography (EEG) is a key component in multichannel emotion recognition systems. In multimodal emotion recognition, fusion of two or more physiological signals such as EEG,

ECG, PPG, GSR, and EMG is commonly employed to enhance classification accuracy. Cranial photoplethysmography (cPPG) is a novel signal acquired through the combination of EEG and PPG, obtained by placing an optical reflectance-type PPG sensor on the prefrontal lobe.

An optical sensor comprising an infrared (IR) light source and an optical detector is positioned on the prefrontal lobe while subjects are exposed to auditory stimuli associated with happy and sad emotions. The cPPG signal is recorded by placing the sensor at the left, central, and right positions of the prefrontal lobe.

The objective of this study is to identify the optimal sensor placement on the prefrontal lobe that provides maximum signal discrimination for accurate emotion detection.<sup>1-10</sup>

## MATERIAL AND METHODS

The CPPG signal is recorded under two emotional states, namely happy and sad. These emotions are elicited by having the subject listen to Hindi songs corresponding to each emotional category for a few minutes. During each emotional stimulus, the CPPG signal is acquired for a duration of 5 seconds.

CPPG sensors are properly positioned on the left, central, and right prefrontal regions of the subject's scalp. For each emotional state, CPPG signals are recorded from all three prefrontal locations.

To ensure high-quality signal acquisition and to minimize the effects of noise and motion artifacts, the subject is instructed to remain still throughout the measurement process.<sup>10-12</sup> System block diagram and subject while signal acquisition is shown in figure 1.

### Statistical Features

CPPG signal is decomposed and features that can discriminate between different activity. The features used include some wavelet based features and some statistical features of CPPG signal. Wavelet Based Features: Mean, variance, Energy, entropy, used as parameters after wavelet decomposition shown in Figure 2.<sup>13-23</sup> CPPG is captured for various emotions. After training the classifier with features calculated from CPPG signals of 10 patients, the KNN classifier was then

tested with the features from 10 specimens that were not included for training the classifier.

The study was carried out in Cummins College of Engineering for Pune, India, the following parameters were recorded before capturing the signal are subject name, age, height, body temperature, blood pressure, heart rate, sugar and SPO2. All the volunteers were healthy for the duration of the experiment as shown in table 1. Oral consent was taken before capturing the data. Data collection was done on subjects in the age group of 20-60 years. A six level wavelet decomposition of CPPG signal is performed using Daubechies 9 and statistical features are calculated. The CPPG signals for happy and sad emotions are decomposed using wavelet transform to different wavelet sub-bands based on their frequency content.

The CCPG signal is acquired using instrumentation amplifier and AVR ATmega 8535 microcontroller is used for digitizing the signal with sampling frequency 100 samples per second and transmitting the data on to the computer. Hardware filters are incorporated to remove the artifact 40 Hz LPF and 50 Hz notch filter. It is on this platform the signal is further processed and analysed.

Support Vector Machines (SVM) linear, K nearest neighbour (KNN) and Artificial Neural Network (ANN) are used to classify the emotions using CPPG signal. After training the classifier with features calculated from CPPG signals of 10 patients, the KNN classifier is tested with the features from 10 specimens that were not included for training the classifier.

Features: Mean, variance, standard deviation, Energy, entropy, used as parameters after wavelet decomposition.<sup>13</sup>

Mean at each decomposition level is calculated using equation (1)<sup>13</sup>

$$\mu_i = \frac{1}{N} \sum_{j=1}^N D_{ij} \quad i = 1, 2, 3, \dots, \dots(1)$$

Standard deviation at each decomposition level is calculated using equation (2)<sup>13</sup>

$$\sigma_i = \left( \frac{1}{N-1} \sum_{j=1}^N (D_{ij} - \mu_i)^2 \right)^{1/2} \quad i = 1, 2, 3, \dots, \dots(2)$$

Energy at each decomposition level is calculated using equation (3)<sup>13</sup>

$$ED_i = \sum_{j=1}^N |D_{ij}|^2 \quad i=1,2,3,\dots, \quad \dots(3)$$

$$EA_i = \sum_{j=1}^N |A_{ij}|^2$$

Where,

N = The number of coefficients of detail or approximation at each decomposition level.

Entropy at each decomposition level is calculated using equation (4).<sup>13</sup>

$$ENT_i = \sum_{j=1}^N D_{ij}^2 \log(D_{ij}^2) \quad \dots(4)$$

Db9 shows similarity with the shape of the normal PPG signal. Therefore, it is chosen for analysis of the CPPG signals. The wavelet function of Daubechies 9 is shown in the Figure 9.

Six level wavelet decomposition of CPPG signal is performed. Spectral analysis of

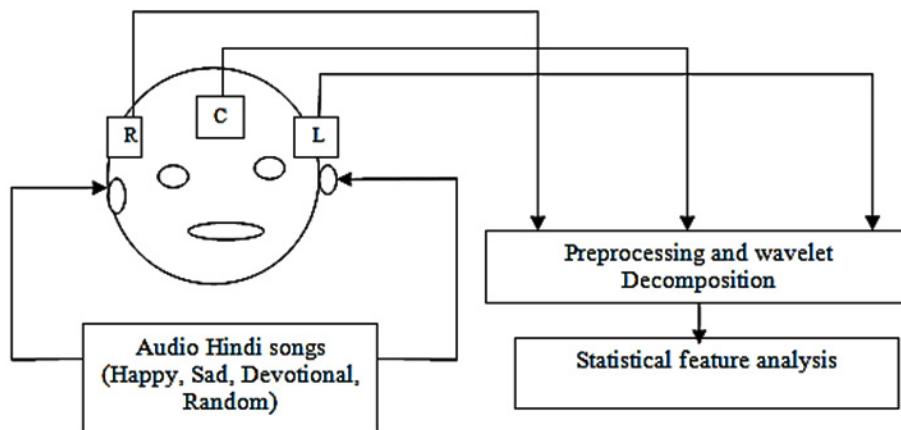


Fig. 1. System Block Diagram

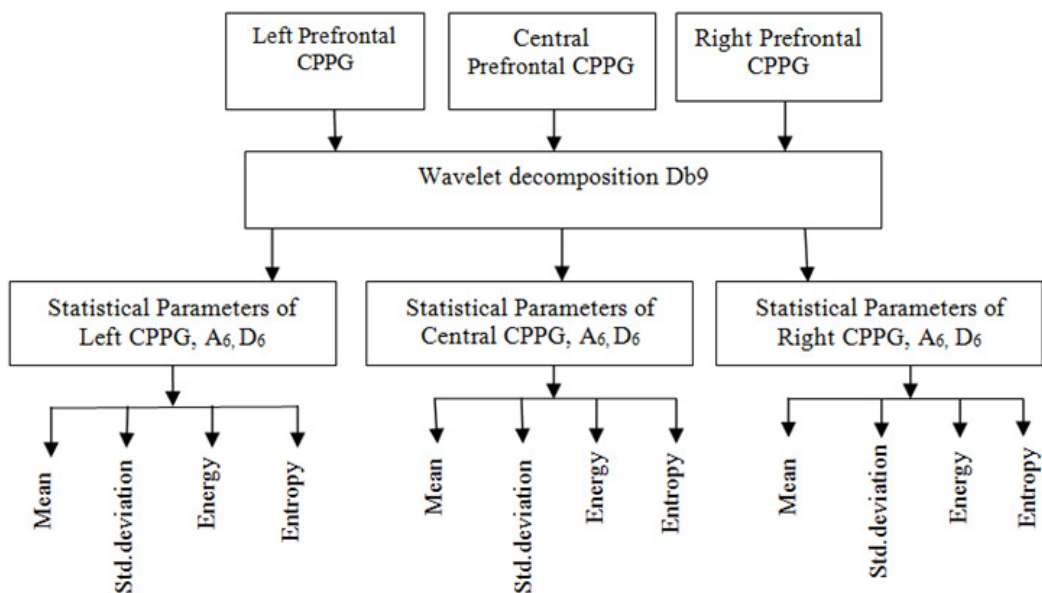


Fig. 2. Multiposition CPPG Signal decomposition and statistical parameters

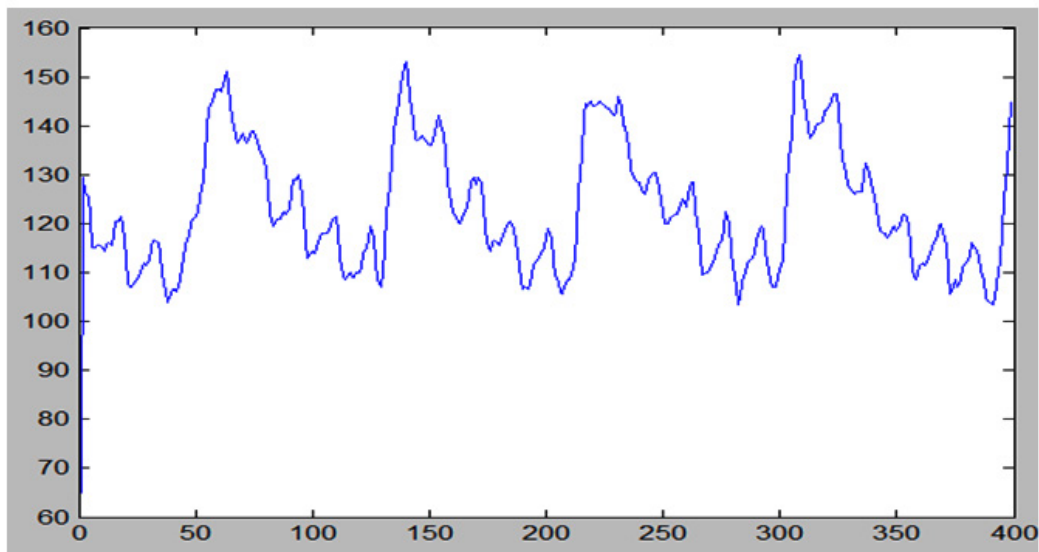
all six levels is performed. The signal frequency is detected in D6 level. Statistical feature of main signal and A6 and D6 are extracted.<sup>13</sup>

The spectral analysis of reconstructed signals it is found that the centre frequency of A6 is

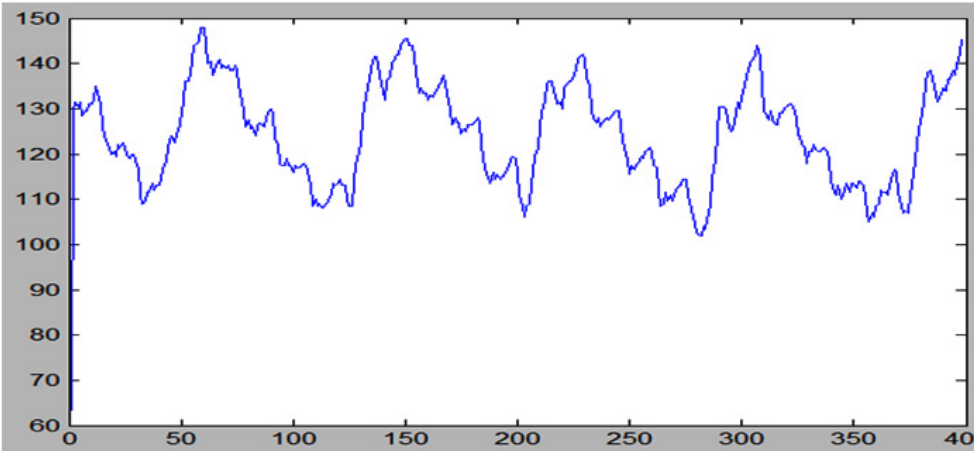
at 1.953 Hz. The higher frequency part of the signal is found in D4 –scale and the centre frequency is 17.58 Hz, D5-9.766Hz and D6- 3.906 Hz. Centre frequency of D1- 140.6 Hz, D2-74.22 and D3 – 46.88 Hz consist of predominantly the noise part

**Table 1.** Parameters Recorded Before CPPG Acquisition

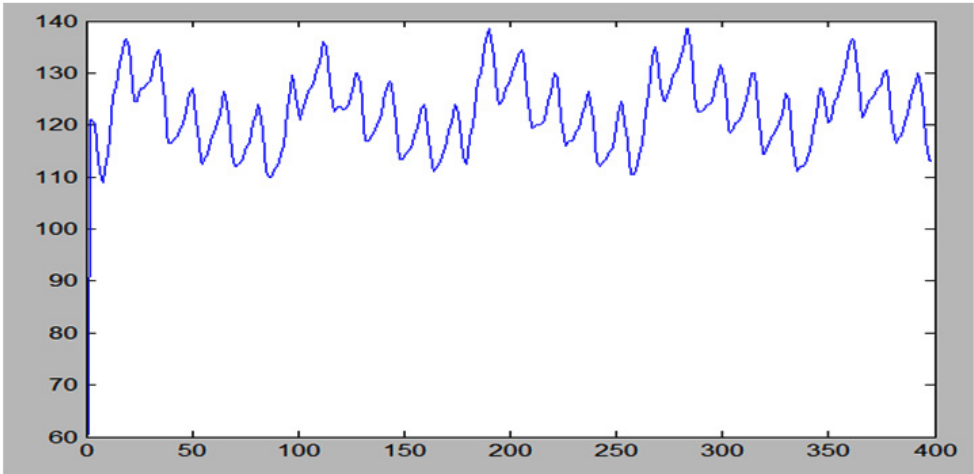
| Subject | Age | Gender | Height (cm) | Weight (Kg) | BPmm Hg | Sugar mg/dL | HRBPM | Body Temp.(°F) | Spo2 (%) |
|---------|-----|--------|-------------|-------------|---------|-------------|-------|----------------|----------|
| 1       | 47  | Female | 164         | 65.2        | 176/93  | 120         | 104   | 93.7           | 99       |
| 2       | 51  | Female | 149         | 59          | 140/80  | 101         | 73    | 92.2           | 98       |
| 3       | 53  | Male   | 149         | 40.8        | 127/60  | 110         | 104   | 91.8           | 99       |
| 4       | 49  | Male   | 170         | 76.5        | 127/80  | 167         | 106   | 93.2           | 99       |
| 5       | 31  | Male   | 169         | 75.4        | 138/91  | 98          | 94    | 91.2           | 99       |
| 6       | 23  | Female | 163         | 50.3        | 136/79  | 100         | 81    | 92.2           | 98       |
| 7       | 46  | Female | 153         | 53.7        | 127/69  | 120         | 100   | 93             | 99       |
| 8       | 33  | Female | 156         | 51          | 108/71  | 107         | 89    | 92.2           | 99       |
| 9       | 39  | Female | 170         | 39          | 128/66  | 115         | 91    | 93.1           | 98       |
| 10      | 28  | Male   | 165         | 67          | 146/101 | 96          | 93    | 93             | 99       |
| 11      | 43  | Female | 161         | 46.9        | 117/74  | 101         | 80    | 92.1           | 98       |
| 12      | 22  | Female | 155         | 53          | 128/93  | 82          | 108   | 91.2           | 98       |
| 13      | 22  | Female | 163         | 59.8        | 122/79  | 87          | 86    | 93.3           | 97       |
| 14      | 36  | Male   | 163         | 91.8        | 132/82  | 110         | 117   | 92.8           | 98       |
| 15      | 21  | Female | 43.6        | 93.3        | 110/79  | 95          | 77    | 93.3           | 98       |
| 16      | 49  | Male   | 163         | 60.5        | 102/72  | 170         | 90    | 93.1           | 98       |
| 17      | 57  | Female | 164         | 76          | 131/68  | 140         | 81    | 93             | 98       |
| 18      | 38  | Female | 163         | 45.5        | 113/77  | 79          | 93    | 93.5           | 93       |
| 19      | 42  | Female | 165         | 74.4        | 115/77  | 91          | 78    | 92.5           | 99       |
| 20      | 32  | Male   | 161         | 64.3        | 127/73  | 98          | 80    | 92.8           | 98       |
| 21      | 33  | Male   | 167         | 70          | 133/75  | 249         | 73    | 92.8           | 99       |



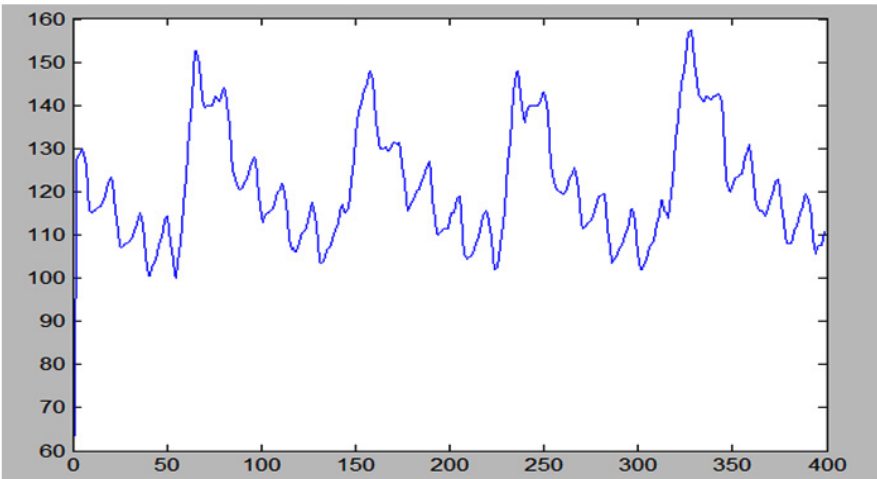
**Fig. 3.** Happy LEFT Prefrontal CPPG



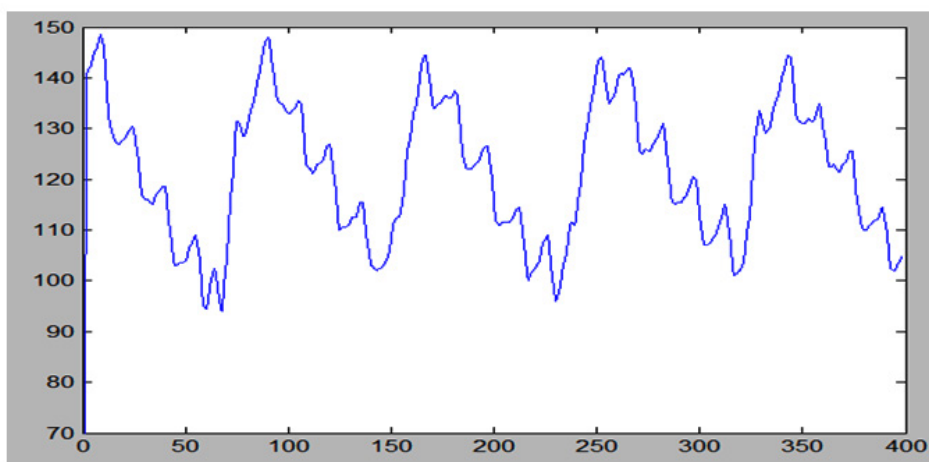
**Fig. 4.** Happy Central Prefrontal CPPG



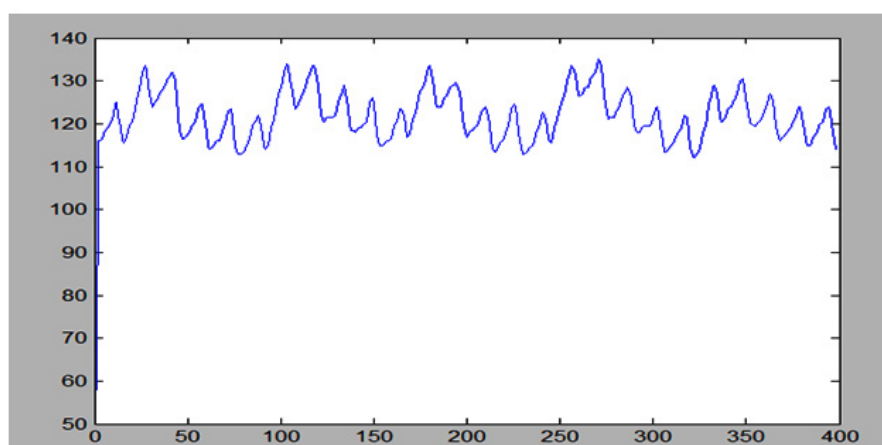
**Fig. 5.** Happy Right Prefrontal CPPG



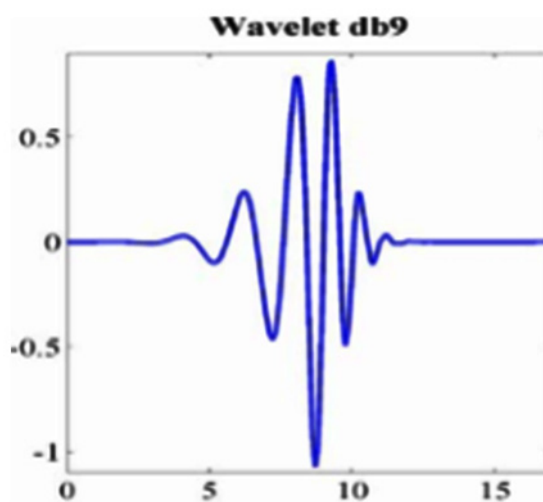
**Fig. 6.** Sad LEFT Prefrontal CPPG



**Fig. 7.** Sad Central Prefrontal CPPG



**Fig. 8.** Sad Right Prefrontal CPPG



**Fig. 9.** Wavelet Function of Daubechies 9

**Table 2.** Statistical Parameters of Left Prefrontal PPG

| Emotion | Mean   | Left Prefrontal PPG |            |              |
|---------|--------|---------------------|------------|--------------|
|         |        | Variance            | Energy     | Entropy      |
| SAD     | 121.50 | 258.19              | 5993139.25 | -57842681.89 |
| HAPPY   | 122.69 | 115.99              | 6052535.75 | -58359672.86 |
| SAD     | 121.44 | 1251.33             | 6382699.00 | -62787104.60 |
| HAPPY   | 117.08 | 4436.93             | 7235298.50 | -74469620.57 |
| SAD     | 123.35 | 176.03              | 6141018.50 | -59347302.77 |
| HAPPY   | 121.67 | 163.15              | 5971241.50 | -57534151.38 |
| SAD     | 126.29 | 1051.62             | 6782334.50 | -66915188.30 |
| HAPPY   | 121.46 | 118.62              | 5933948.75 | -57102198.69 |
| SAD     | 122.30 | 164.24              | 6033766.25 | -58199318.32 |
| HAPPY   | 125.82 | 95.33               | 6354586.50 | -61558914.31 |
| SAD     | 120.93 | 176.63              | 5905765.50 | -56852170.75 |
| HAPPY   | 122.91 | 165.76              | 6093346.50 | -58834470.02 |
| SAD     | 123.90 | 186.96              | 6199764.00 | -59981930.14 |
| HAPPY   | 123.19 | 271.47              | 6163226.00 | -59655984.38 |
| SAD     | 121.62 | 77.65               | 5932345.50 | -57052965.90 |
| HAPPY   | 124.20 | 166.74              | 6221614.25 | -60198825.77 |
| SAD     | 120.21 | 115.83              | 5811880.00 | -55805411.63 |
| HAPPY   | 122.55 | 56.94               | 6015181.00 | -57914536.77 |
| SAD     | 125.77 | 180.89              | 6383732.75 | -61939565.95 |
| HAPPY   | 121.89 | 158.32              | 5990628.75 | -57735845.53 |

**Table 3.** Statistical Parameters of Central Prefrontal PPG

| Emotion | Mean   | Central Prefrontal PPG |            |              |
|---------|--------|------------------------|------------|--------------|
|         |        | Variance               | Energy     | Entropy      |
| SAD     | 117.98 | 490.98                 | 5749671.50 | -55449269.20 |
| HAPPY   | 124.69 | 425.87                 | 6372786.75 | -62023464.36 |
| SAD     | 122.69 | 861.06                 | 6348831.75 | -62135940.83 |
| HAPPY   | 114.33 | 421.21                 | 5383184.00 | -51526512.95 |
| SAD     | 121.23 | 185.63                 | 5937802.25 | -57196190.36 |
| HAPPY   | 124.30 | 128.21                 | 6215475.75 | -60102292.73 |
| SAD     | 125.22 | 225.11                 | 6345862.25 | -61568915.50 |
| HAPPY   | 123.48 | 160.45                 | 6147902.50 | -59407911.58 |
| SAD     | 121.80 | 169.15                 | 5986897.25 | -57703230.42 |
| HAPPY   | 123.76 | 613.97                 | 6355847.50 | -61992517.56 |
| SAD     | 123.62 | 91.12                  | 6133529.75 | -59201761.91 |
| HAPPY   | 122.67 | 243.22                 | 6101333.50 | -58984357.10 |
| SAD     | 126.12 | 678.48                 | 6616660.00 | -64827108.74 |
| HAPPY   | 123.25 | 474.64                 | 6250374.25 | -60755524.91 |
| SAD     | 119.68 | 85.84                  | 5748726.25 | -55114393.04 |
| HAPPY   | 121.11 | 58.68                  | 5875524.50 | -56434863.17 |
| SAD     | 123.89 | 163.77                 | 6189172.75 | -59849542.52 |
| HAPPY   | 123.22 | 453.04                 | 6238078.75 | -60611195.63 |
| SAD     | 119.68 | 85.84                  | 5748726.25 | -55114393.04 |
| HAPPY   | 121.11 | 58.68                  | 5875524.50 | -56434863.17 |

of the signal. The signal frequency is detected in D6 and A6 level. Statistical feature of main signal and A6 and D6 are extracted.

## RESULTS

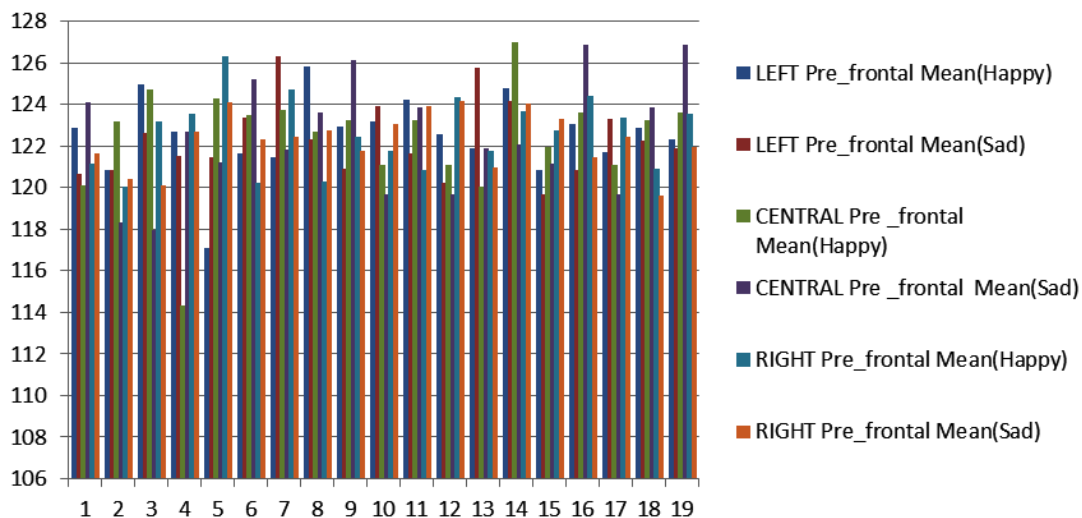
CPPG (Cranial Photoplethysmogram) for different emotions are shown in Figure 3 to Figure

8. Table 2, Table 3 and Table 4 shows the statistical parameters of left central and right Prefrontal PPG Signal.

Table 5, Table 6 and Table 7 shows the statistical features. Box plots provide a visualization of summary statistics for sample data which is nothing but the statistical parameters for each CPPG of the three positions for a number

**Table 4.** Statistical Parameters of Right Prefrontal PPG

| Emotion | Mean   | Right Prefrontal PPG |            |              |
|---------|--------|----------------------|------------|--------------|
|         |        | Variance             | Energy     | Entropy      |
| SAD     | 121.65 | 62.25                | 5929380.00 | -57009034.48 |
| HAPPY   | 121.16 | 56.82                | 5879506.25 | -56475762.62 |
| SAD     | 120.41 | 745.83               | 6081507.25 | -59173711.44 |
| HAPPY   | 120.02 | 226.05               | 5837606.75 | -56168627.94 |
| SAD     | 120.10 | 1121.57              | 6201227.25 | -60764754.48 |
| HAPPY   | 123.20 | 111.51               | 6100548.00 | -58865566.59 |
| SAD     | 122.71 | 104.26               | 6049464.50 | -58316793.34 |
| HAPPY   | 123.57 | 73.62                | 6121497.00 | -59058573.28 |
| SAD     | 124.11 | 1380.30              | 6694805.00 | -66230731.17 |
| HAPPY   | 126.34 | 779.94               | 6679131.75 | -65570404.48 |
| SAD     | 122.32 | 244.06               | 6067493.25 | -58621569.11 |
| HAPPY   | 120.23 | 109.37               | 5811590.25 | -55798019.33 |
| SAD     | 122.45 | 519.28               | 6189147.00 | -60137348.55 |
| HAPPY   | 124.73 | 307.32               | 6329844.25 | -61466021.15 |
| SAD     | 122.77 | 185.15               | 6087916.25 | -58791822.09 |
| HAPPY   | 120.29 | 62.86                | 5798853.25 | -55625779.55 |
| SAD     | 121.79 | 38.21                | 5933568.25 | -57033698.85 |
| HAPPY   | 122.42 | 53.50                | 6001315.50 | -57764969.89 |
| SAD     | 123.03 | 48.42                | 6059063.25 | -58374528.52 |
| HAPPY   | 121.77 | 161.12               | 5980902.50 | -57633818.45 |



**Fig. 10.** Variation of Multiposition Mean for Happy and Sad Emotions

of subjects. The sample data is calculated for 21 subjects for happy and sad the box-plots are plotted. Each box-plot contains the following features:

## DISCUSSIONS

### Statistical Analysis at Central Prefrontal CPPG

For central PPG signal mean and variance values for happy are 124.69 and 425.87 respectively and for sad 117.98 and

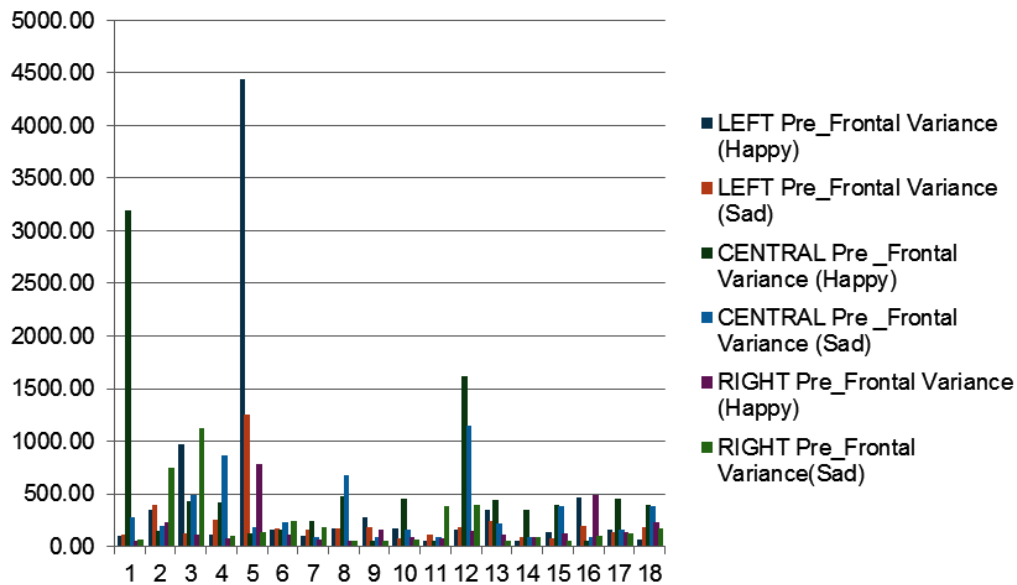


Fig. 11. Variation of Multiposition Variance for Happy and Sad Emotions

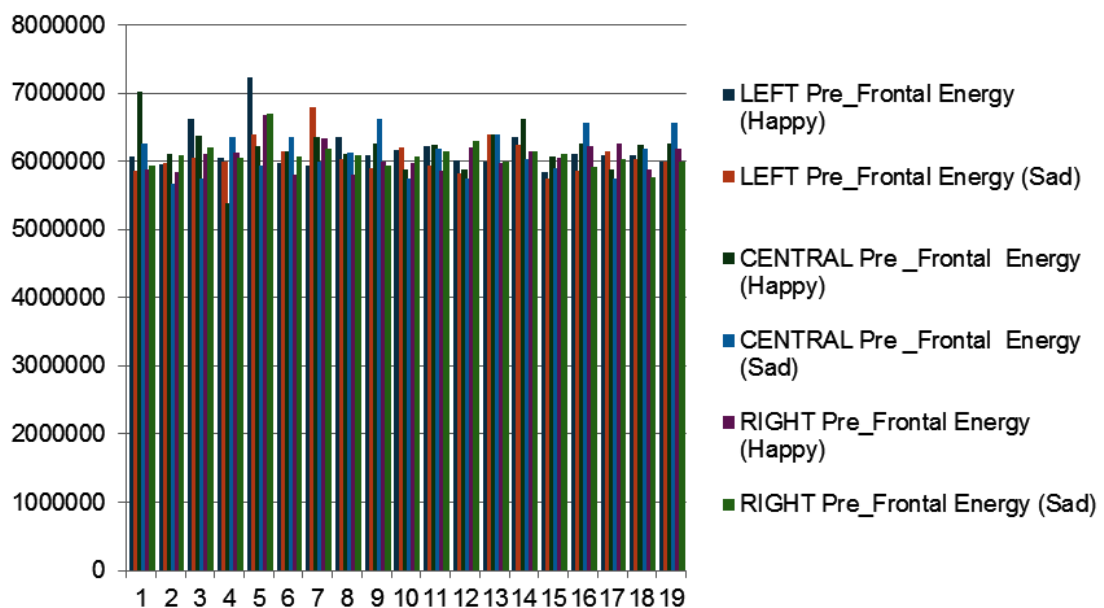


Fig. 12. Variation of Multiposition Energy for Happy and Sad Emotions

490.98 respectively. Difference in mean between Happy and Sad is 6.71 and difference in variance between Happy and Sad 65.11 .

For central  $A_6$  scale mean and variance values for happy are 934.02 and 6357 respectively and for sad 969.568 and 3432.34 respectively. Difference in mean between Happy and Sad is 35.58 and difference in variance between Happy and Sad 2924.66.

**Table 5.** Statistical values of Central Prefrontal CPPG signal

| Central Prefrontal CPPG          |              |            |
|----------------------------------|--------------|------------|
| Statistical Parameter            | Happy        | Sad        |
| Mean                             | 123.083      | 122.687    |
| Variance                         | 421.207      | 225.108    |
| Energy                           | 15665.1      | 15548.2    |
| Entropy                          | -6.0066E+007 | -6.02E+007 |
| <b>Central: <math>A_6</math></b> |              |            |
| Mean                             | 934.02       | 969.568    |
| Variance                         | 6357         | 3432.34    |
| Energy                           | 899187       | 962977     |
| Entropy                          | -2.27E+008   | -2.99E+008 |
| <b>Central: <math>D_6</math></b> |              |            |
| Mean                             | 6337.6       | 4585.37    |
| Variance                         | 7.55E+007    | 4.15E+007  |
| Energy                           | 6337.6       | 4585.37    |
| Entropy                          | -4.99E+010   | -2.24E+010 |

**Table 6.** Statistical values of Left Prefrontal CPPG signal

| Left Prefrontal CPPG          |             |             |
|-------------------------------|-------------|-------------|
| Statistical Parameter         | Happy       | Sad         |
| Mean                          | 122.885     | 121.617     |
| Variance                      | 162.895     | 176.625     |
| Energy                        | 15272.3     | 15095.2     |
| Entropy                       | -5.89E+007  | -5.813E+007 |
| <b>Left: <math>A_6</math></b> |             |             |
| Mean                          | 940.053     | 944.013     |
| Variance                      | 3354.72     | 1969.59     |
| Energy                        | 884758      | 891916      |
| Entropy                       | -2.69E+008  | -2.67E+008  |
| <b>Left: <math>D_6</math></b> |             |             |
| Mean                          | 2996.35     | 2640.63     |
| Variance                      | 1.711E+007  | 1.6025E+007 |
| Energy                        | 3178.28     | 2688.58     |
| Entropy                       | -1.122E+010 | -8.99E+009  |

For central  $D_6$  scale mean and variance values for happy are 6337.6 and 9.228E+006 respectively and for sad 1915.01 and 8.085E+006 respectively. Difference in mean between happy and sad is 4422.59. For central  $D_6$  scale difference in variance between Happy and Sad is 1.14E+006.

For central PPG signal energy and entropy values for happy are 6372786.75 and -62023464.36 respectively and for sad 5749671.50 and -55449269.20 respectively. Difference in energy between Happy and Sad is 623115.25 and difference in entropy between Happy and Sad is 6.57E+006

For central  $A_6$  scale energy and entropy values for happy are 899187 and -2.647E+008 respectively and for sad 892011 and -2.735E+008 respectively. Difference in energy between Happy

**Table 7.** Statistical Values of Right Prefrontal CPPG Signal

| Left Prefrontal CPPG           |              |              |
|--------------------------------|--------------|--------------|
| Statistical Parameter          | Happy        | Sad          |
| Mean                           | 122.749      | 122.325      |
| Variance                       | 114.271      | 123.875      |
| Energy                         | 15165.2      | 15196.2      |
| Entropy                        | -5.8315E+007 | -5.8374E+007 |
| <b>Right: <math>A_6</math></b> |              |              |
| Mean                           | 937.214      | 944.294      |
| Variance                       | 1295.76      | 2580         |
| Energy                         | 879257       | 892011       |
| Entropy                        | -2.647E+008  | -2.735E+008  |
| <b>Right: <math>D_6</math></b> |              |              |
| Mean                           | 2156.49      | 1915.01      |
| Variance                       | 9.228E+006   | 8.085E+006   |
| Energy                         | 15665.1      | 15548.2      |
| Entropy                        | -5.34E+009   | -4.38E+009   |

**Table 8.** F-Test Two-Sample for Variances

| F-Test Two-Sample for Variances |             |             |
|---------------------------------|-------------|-------------|
|                                 | Variable 1  | Variable 2  |
| Mean                            | 526.3161087 | 323.7651451 |
| Variance                        | 562277.6722 | 89496.79592 |
| Observations                    | 18          | 18          |
| df                              | 17          | 17          |
| F                               | 6.282657009 |             |
| P(F<=f) one-tail                | 0.000220186 |             |
| F Critical one-tail             | 2.271892889 |             |

and Sad is 7176 and difference in entropy between Happy and Sad is  $8.8E+006$ .

For central  $D_6$  scale energy and entropy values for happy 6337.6 and  $9.228E+006$  respectively and for sad 1915.01 and  $8.085E+006$  respectively. For central D6 scale difference in energy between happy and sad 4422.59 and difference in entropy between Happy and Sad is  $1.14E+006$ .

#### Statistical Analysis at Left Prefrontal CPPG

For left PPG signal mean and variance values for happy are 122.69 and 115.99 respectively and for sad are 121.50 and 258.19 respectively. Difference in mean between Happy and Sad is 1.19 and difference in variance between happy and sad 142.2.

For left  $A_6$  scale mean and variance values for happy are 940.053 and 3354.72 respectively and for sad are 944.013 and 1969.59 respectively. Difference in mean between Happy and Sad is 3.96

and difference in variance between happy and sad 1385.13.

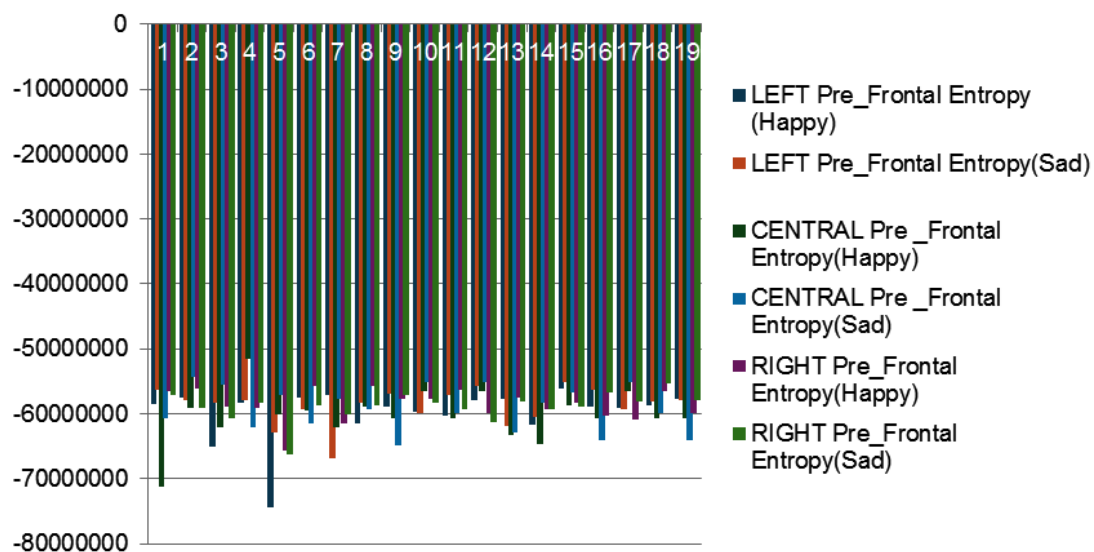
For left D6 scale mean and variance values for happy are 2996.35 and  $1.711E+007$  respectively and for sad are 2640.63 and  $1.6025E+007$  respectively. Difference in mean between happy and sad is 355.72 and difference in variance between Happy and Sad is  $1.08E+006$ .

For left PPG signal energy and entropy values for happy are 6052535.75 and -58359672.86 respectively and for sad are 5993139.25 and -57842681.89 respectively. Difference in energy between Happy and Sad is 59396.25 and difference in entropy between Happy and Sad  $5.16E+005$ .

For left  $A_6$  scale energy and entropy values for happy are 884758 and  $-2.69E+008$  respectively and for sad are 891916 and  $-2.67E+008$  respectively. Difference in energy between Happy and Sad is 7158 and difference in entropy between Happy and Sad  $2.0E+006$ .

**Table 9.** Classification Report

| Classifier | TP | TN | FP | Classification Report |             |                |                |
|------------|----|----|----|-----------------------|-------------|----------------|----------------|
|            |    |    |    | FN                    | Accuracy(%) | Sensitivity(%) | Specificity(%) |
| KNN        | 4  | 3  | 1  | 2                     | 70          | 66.66          | 75             |
| SVM Linear | 2  | 3  | 3  | 2                     | 50          | 50             | 50             |
| ANN        | 3  | 3  | 2  | 2                     | 60          | 60             | 60             |



**Fig. 13.** Variation of Multiposition Entropy for Happy and Sad Emotions

For left D<sub>6</sub> scale energy and entropy values for happy are 3178.28 and -1.122E+010 respectively and for sad are 2688.58 and -8.99E+009 respectively. Difference in energy between Happy and Sad is 489 and difference in entropy between Happy and Sad is 2.23E+009.

#### **Statistical Analysis at Right Prefrontal CPPG(pending)**

For right A<sub>6</sub> scale mean and variance values for happy are 937.214 and 1295.76 respectively and for sad are 944.294 and 2580 respectively. Difference in mean between Happy and Sad is 7.08 and difference in variance between happy and sad is 1284.24.

For right A<sub>6</sub> scale mean and variance values for happy are 937.214 and 1295.76 respectively and for sad are 944.294 and 2580 respectively. Difference in mean between Happy and Sad is 7.08 and difference in variance between happy and sad is 1284.24.

For right D<sub>6</sub> scale mean and variance values for happy are 2156.49 and 9.228E+006 respectively and for sad are 1915.01 and 8.085E+006 respectively. Difference in mean between happy and sad is 241.48 and difference in variance between Happy and Sad is 1.143E+006.

For right A<sub>6</sub> scale energy and entropy values for happy are 879257 and -2.647E+008 respectively and for sad are 892011 and -2.735E+008 respectively. Difference in energy between Happy and Sad is 12754 and difference in entropy between Happy and Sad 9.0 E+006.

For right A<sub>6</sub> scale energy and entropy values for happy are 879257 and -2.647E+008 respectively and for sad are 892011 and -2.735E+008 respectively. Difference in energy between Happy and Sad is 12754 and difference in entropy between Happy and Sad 9.0 E+006.

For right D<sub>6</sub> scale energy and entropy values for happy 15665.1 and -5.34E+009 respectively and for sad 15548.2 and -4.38E+009 respectively. Difference in energy between Happy and Sad is 116.9 and difference in entropy between Happy and Sad is 9.6E+008.

The CPPG signals for happy and sad emotions are decomposed using wavelet transform to different wavelet sub-bands based on their frequency content. Support Vector Machines (SVM) linear, K nearest neighbour (KNN) and

ANN are used to classify the emotions using CPPG signal..

For all feature comparisons f-Test two sample for variances is carried out with  $\alpha=0.05$  and p value =0.00022 is shown in Table 8. The accuracy of the KNN classifier is observed to be 80%, SVM classifier 60% and ANN classifier 70%. Results are shown in Table 9.

## **CONCLUSION**

The signal is recorded at three positions: left, central and right prefrontal position. The signal is decomposed at sixth level by Daubechies wavelet, level as the central frequency of 6<sup>th</sup> level matches with signal frequency. After sixth level decomposition statistical analysis was done. The above analysis reveals that these multi position, subbands level statistical features can help to detect and localize the activity and emotions. It is observed that statistical values are different for different emotions. As the difference in the statistical parameters was found to be more in central prefrontal PPG with respect to left and right prefrontal PPG. So the features of central PPG can be used for classification of emotions. It reduces the data base and system complexity for optimal result.

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**Data Availability Statement**

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**Ethics Statement**

Verbal consent was recorded from the participants before participating in this study.

**Informed Consent Statement**

This study did not involve human participants, and therefore, informed consent was not required.

**Clinical Trial Registration**

This research does not involve any clinical trials.

**Permission to reproduce material from other sources**

Not Applicable.

**Author Contributions**

Nivedita Daimiwal: Conceptualization, Methodology, Writing – Original Draft, Data Acquisition, Analysis; Revati Shriram: Formal Analysis, Validation, Writing – Review & Editing

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