Study of Emotional Variability Using Photoplethysmogram Signal

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***Abstract*—This study investigates the feasibility of photoplethysmogram (PPG) signals in recognizing variability in human's funny, fear and sad emotions. Undoubtedly, Easy Pulse data acquisition device which is used to perceive the PPG signals have superior criterions which are small in size, low power consumption as well as low in cost. Thus, this study will prove the robustness and reliability of PPG signals as an emotion recognition mechanism. A total of ten subjects were chosen randomly which ranged from twenty-one to twenty-four years old. A total of five male and five female students were given three different videos to stimulate different emotions during the given time. Easy Pulse sensor, which has the ability in filtering the unwanted signals has made the study easier. Discriminative features are then extracted from the PPG morphology. PPI, maximum amplitude, as well as the Cardioid pattern of the signals. Finally, four methods of classification have been used to identify the variability in emotions. PPI, maximum amplitude, area and maximum radius of the Cardioid loop were used as the classifiers. These methods have clearly shown great results in differentiating between funny, fear and sad emotions. It was discovered that every human has different rate of sensitivity to fear and sad. Some have the tendency to be very sensitive to fear and some to sad. The experimental results demonstrated that the physiological signals such as PPG have great potentials where the system provides high classification performance.**

***Index Terms*—Cardioid Method; Emotional Variability; Maximum Amplitude Method; PPG; PPI Method.**

I. INTRODUCTION

There are six basic emotions which are happiness, sadness, surprise, fear, disgust and anger [1]. Health Psychology is a scientific study on how psychological, behavioral, stress and emotional issues influence physical health [2]. Stress and a few additional negative factors give a big impact to human well-being [3]. The characteristic of the stress perceives an individual an overwhelming or threatening events to one's well-being.

Most of the crimes reported were mainly due to failure in controlling one's emotion. The aforementioned cases [4, 5, 6] that have been recorded show the importance of this emotional recognition research. This is because, if the individual's emotion can be detected earlier, crimes can be prevented. The outer emotion of an individual definitely does not reflect the real or true emotion of that person. Thus, in this study, an emotion detection technique will be proposed.

Based on previous research studies, there are a few types of method that have been used to detect emotional variability which are EEG, ECG, SKT and GSR [7, 8, 9, 10, 11]. Biosignals such as EEG, ECG and PPG itself have gained the attention of researchers from all around the world. This is due to the ability of these signals to accurately represent our true reactions. Recently, PPG signals which are closely related to our vital sign such as heart rate and blood pressure are used to recognize emotional differences.

PPG pulse is divided into two main points which are systolic and diastolic as shown in Figure 1 [12]. PPG which uses infrared light is intended to estimate the movement of blood underneath the skin. Apart from that, PPG can also measure oxygen saturation, blood pressure, cardiac output, heart rate and accessing autonomic function. The overview on how light is travelled inside human's skin is shown in Figure 2 [13]. This wave reflects the blood flow in the human vessel. In wave-like motion, the blood flows from the heart to the fingertips and toes. Most studies use fingertips as the point of detection. This is due to the effectiveness of this point for which the skin at the fingertip is very thin. In addition, light can easily flow through the fingertip.

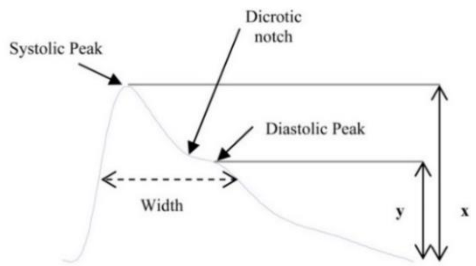

Figure 1: PPG Waveform [12]

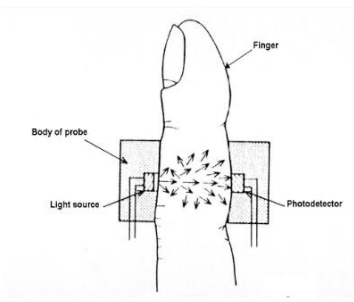

Figure 2: Transmission of light in human's skin[13]

Among the advantages of choosing PPG over other biosignals are inexpensive, low power consumption and small in size.

II. EXPERIMENTATION AND RESULTS

This study uses four steps to develop an emotion variability detection using PPG signal which are signal acquisition, pre-processing, feature extraction and classification. Funny, fear and sad are the three emotions to be recognized.

Ten PPG signals were acquired from five male and five female students ranged from 21 to 24 years old. They were given three videos that were presumed to stimulate funny, fear and sad emotions. The videos watched by the respondents were the “Compilation of Babies Laughing” [14], “Saw 7” [15] and “Doa Untuk Kedua Ibu Bapa” [16] for funny, fear and sad respectively.

Figure 3: “Compilation of Babies Laughing” [14]

Figure 4: “Saw 7” [15]

Figure 5: “Doa Untuk Kedua Ibu Bapa” [16]

Before the video watching session, an Easy Pulse sensor was placed at their fingertip. The respondents were not allowed to move once the CoolTerm software began the data acquisition. An Easy Pulse and an Arduino based processing board were used as the hardware to acquire the data needed. During the signal acquisition stage, filtering process for the acquired data is performed inside the easy pulse board. The unique feature of the easy pulse board that has the preinstalled bandpass filter produced a noise free PPG signal. The following Figure 6 and Figure 7 display two of the filtered signals obtained from the respondents. The Arduino processer then transmits data from the Easy Pulse board to the CoolTerm software to be displayed.

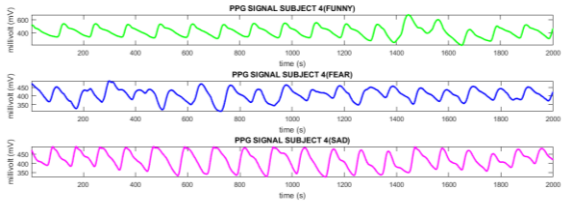

Figure 6: PPG Signal for Subject 4

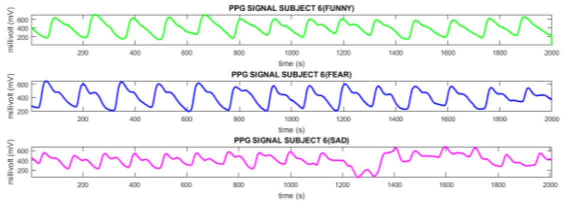

Figure 7: PPG Signal for Subject 6

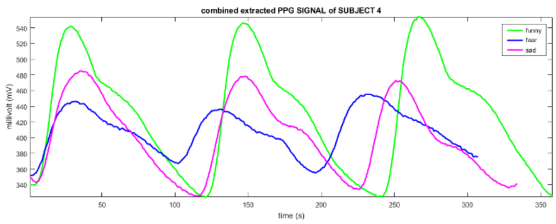

Figure 8: Combined extracted PPG signal of Subject 4

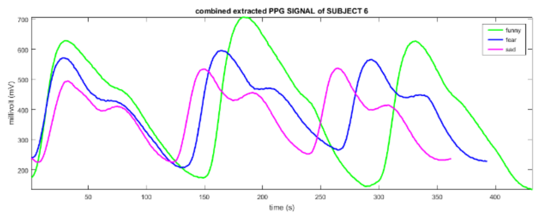

Figure 9: Combined extracted PPG signal of Subject 6

Once the filtered PPG signal have been acquired from the previous step, its feature was extracted using MATLAB R2016b and will be observed and analysed in the next step, called decision making. The peak values and the interval for one complete cycle of the signal is essential in determining the variability in human’s emotion. Three consecutive cycles of the signal have been extracted and overlapped with each other into one graph as shown in Figure 8 and Figure 9. Based on these figures, extracted signals for each subjects show that for every cycle of each emotions, the intervals for a complete cycle are different. Thus, making the overlapped or combined graph of each features having slightly different in time intervals for every emotion.

In this study, three feature extraction patterns have been applied and four statistical methods were used for the classification. The first pattern is by overlapping the previous extracted three cycles into one, in order to calculate the average of the maximum amplitude using MATLAB R2016b. These signals are illustrated as in figures 10 until 15. The average of these three peaks is calculated to be compared between the three emotions and the average maximum amplitude for all subjects have been summarized in Table 1. From Table 1, Vmax1, Vmax2 and Vmax3 are the amplitudes for funny, fear and sad emotion respectively. As clear as the values shown in the table, the study concluded that if the subject is in a happy state or in this case they are experiencing funny emotion, 90% of the subjects have higher value of amplitude compared to fear and sad emotion. In contrast, data summarized in Table 1 demonstrates that 70% of the subjects turned out to be more sensitive to fear rather than sad emotion while the other 30% indicates the opposite.

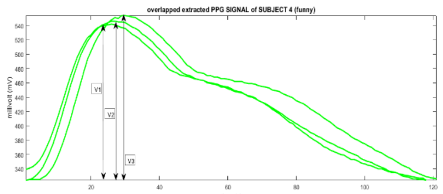

Figure 10: Overlapped Extracted PPG Signal of Subject 4 (FUNNY)

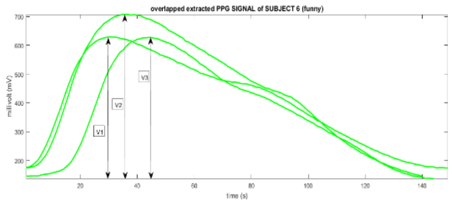

Figure 11: Overlapped Extracted PPG Signal of Subject 6 (FUNNY)

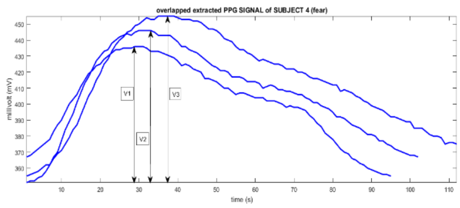

Figure 12: Overlapped Extracted PPG Signal of Subject 4 (FEAR)

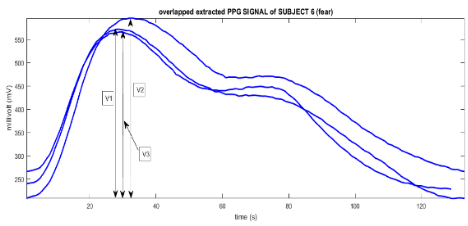

Figure 13: Overlapped Extracted PPG Signal of Subject 6 (FEAR)

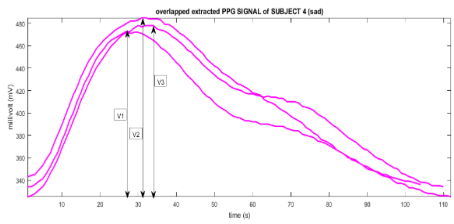

Figure 14: Overlapped Extracted PPG Signal of Subject 4 (SAD)

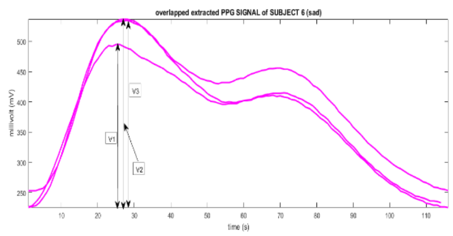

Figure 15: Overlapped Extracted PPG Signal of Subject 6 (SAD)

The second pattern is done by extracting three cycles from the original signals to observe the PPI and will be based on the following figures 16 until 21. To calculate PPI from the extracted signals, the average of the two successive PPI has been calculated and the following Eq. (1) is used.

$$PPI = \frac{(x_3 - x_2) + (x_2 - x_1)}{2} \tag{1}$$

where, x_1, x_2, x_3 are three consecutive locations for the three peaks extracted earlier.

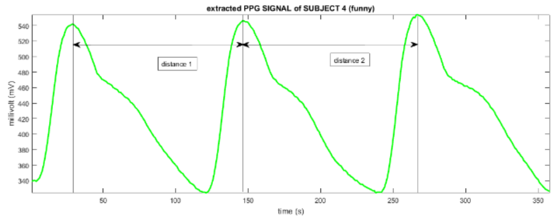

Figure 16: Extracted PPG Signal of Subject 4 (FUNNY)

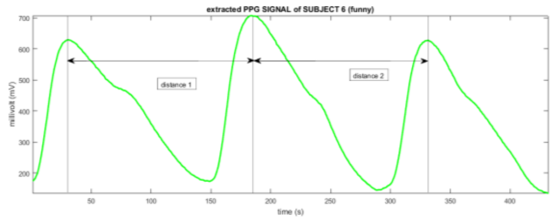

Figure 17: Extracted PPG Signal of Subject 6 (FUNNY)

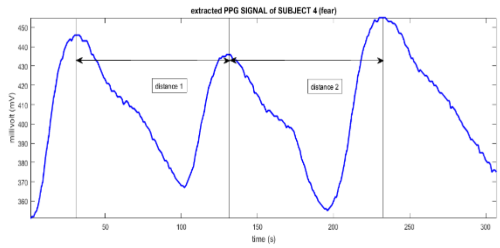

Figure 18: Extracted PPG Signal of Subject 4 (FEAR)

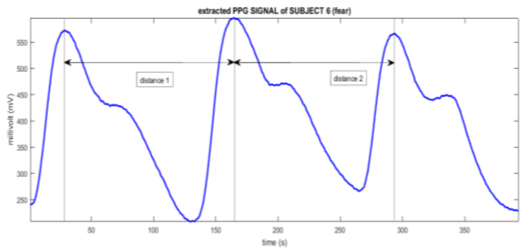

Figure 19: Extracted PPG Signal of Subject 6 (FEAR)

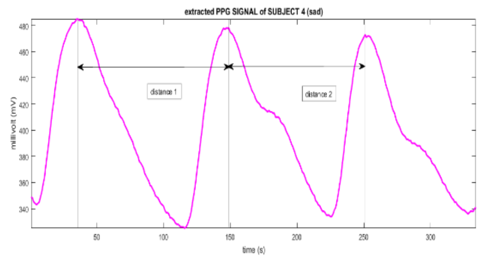

Figure 20: Extracted PPG Signal of Subject 4 (SAD)

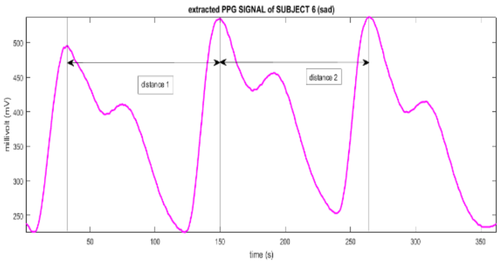

Figure 21: Extracted PPG Signal of Subject 6 (SAD)

The value of the calculated PPI is summarized in Table 2. PPI1, PPI2 and PPI3 represent the PPIs for funny, fear and sad respectively. In this classification, 40% of the subjects illustrated sensitivity to the funny emotion, followed by fear and sad. However, the method of using PPI as a classifier in this study can be claimed as inconclusive due to the failure in differentiating fear and sad emotions according to the reading of PPI2 and PPI3 which fluctuates randomly, making it hard to be differentiated.

The last pattern is by creating the Cardioid based graph to determine the area enclosed by the loop as well as its maximum radius or the Euclidean distance. Originally, the PPG signal can be represented by x(t) as in Equation (2).

$$x(t) = \{x(1), x(2), x(3), \ldots, x(n)\} \tag{2}$$

where, *x(t)* = PPG waveforms

n = total number of points with respect to the x-axis for the three consecutive cycles

To obtain the points to form the Cardioid, x(t) is then differentiated as in Equation (3).

$$y(t) = x(n) - (x(n-1)) \tag{3}$$

where *t* = *1, 2, 3, . . . , (n-1)* and *y(t)* = the differentiated PPG dataset.

From the third pattern of feature extraction, two classifications can be inferred. First classification is the area of the Cardioid, followed by the Euclidean distance. With the aid of MATLAB R2016b, the area of the cardioid loop is obtained using the 'polyarea' function. Two dimensional closed loop graph is then plotted. In order to determine the area of the Cardioid, the three cycles extracted in the previous figures have been plotted as in the following figures 22 until 27.

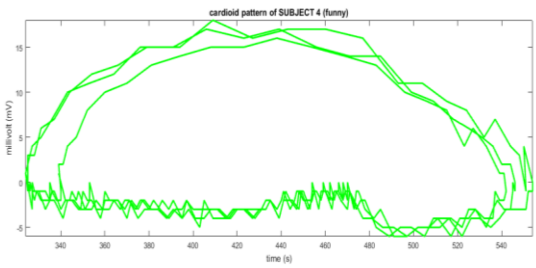

Figure 22: Cardioid Pattern of Subject 4 (FUNNY)

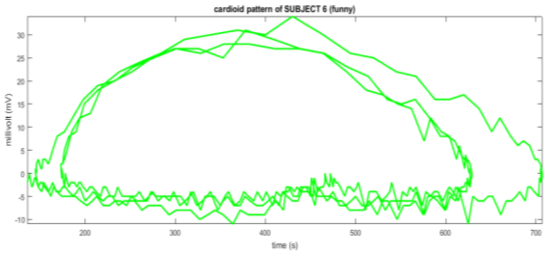

Figure 23: Cardioid Pattern of Subject 6 (FUNNY)

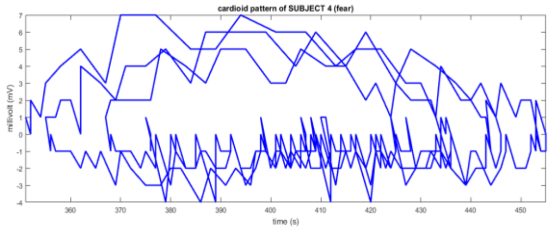

Figure 24: Cardioid Pattern of Subject 4 (FEAR)

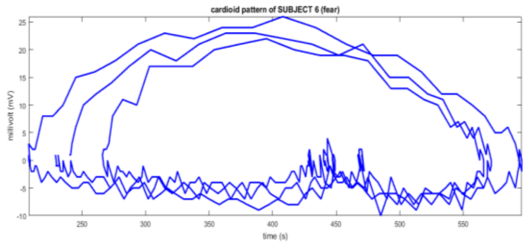

Figure 25: Cardioid Pattern of Subject 6 (FEAR)

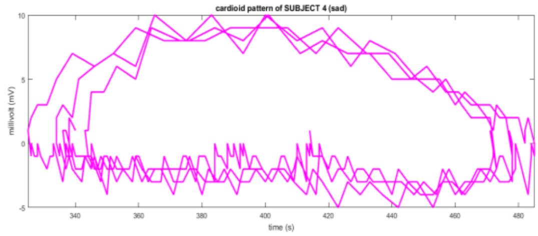

Figure 26: Cardioid Pattern of Subject 4 (SAD)

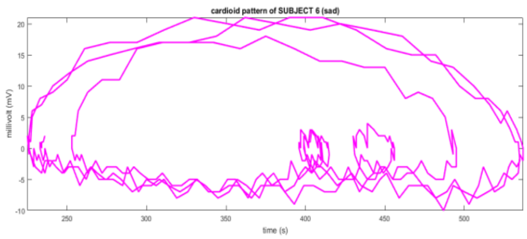

Figure 27: Cardioid Pattern of Subject 6 (SAD)

The area of each emotions is calculated and the cardioid pattern for all emotions will be overlapped with each other to give a clearer overview of the difference in the area of all emotions as shown in Figure 28 and Figure 29.

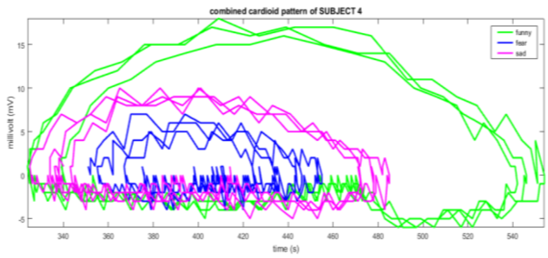

Figure 28: Combined Cardioid Pattern of Subject 4

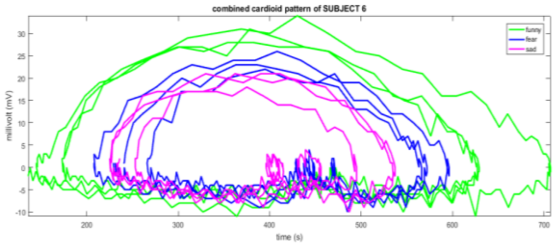

Figure 29: Combined Cardioid Pattern of Subject 6

As clear as Figure 28 and Figure 29 show, the green pattern for all subjects have the biggest area compared to pink and blue. The green loops that indicate the funny state of the subjects have the widest area compared to fear and sad. On the other hand, the area of the blue and pink pattern represents fear and sad respectively.

The area of each emotion for all subjects are summarized in Table 3. AX, AY and AZ represents the area of funny, fear and sad respectively. Referring to this method of classification, the study infers its effectiveness in recognizing the three states of emotion. The data summarized in Table 3 shows a 100% success rate in differentiating funny with fear and sad. In contrast, 70% of the results show that the second biggest area of the Cardioid are from fear emotion and the remaining represents the sad emotion. Thus, the outcomes suggest that this method is a good classification technique which can be used to recognize different emotions.

The final classification is by determining the Euclidean distance of the Cardioid loop. This distance has shown a great impact in the classification process of this research.

Equation (4) is used to find the centroid and the centroid position is denoted by (cx,cy).

$$(cx, cy) = \left[\frac{\sum_{i=1}^{n} x(i)}{n}, \frac{\sum_{i=1}^{n} y(i)}{n}\right] \quad (4)$$

After obtaining the centroid, the Euclidean distances are then computed using Equation (5).

$$\mathrm{ed(i)} = \sqrt{(\mathrm{cx} - \mathrm{x(i)})^2 + (\mathrm{cy} - \mathrm{y(i)})^2} \quad (5)$$

where *ed(i) = ed1, ed2, ed3, . . . , ed(n).*

Table 4 summarized the maximum radius of Cardioid loop for all subjects for the three state of emotions. From the data collected, this method shows a 100% success rate of classifying the funny emotion. This technique also managed to prove a 90% success rate of recognizing fear emotions. To top it off, a 90% success rate was achieving with the sad emotion.

Table 1
Maximum amplitude for all subjects for funny, fear and sad emotions

SUBJECT	Vmax1	Vmax2	Vmax3
1	687.3333	560.6667	504.6667
2	564.3333	454.3333	527.6667
3	568	447.6667	519.3333
4	547.3333	445.6667	478.6667
5	549.3333	525	458.3333
6	654.3333	578	522.3333
7	648	503.3333	543.6667
8	625.3333	532	573
9	544.3333	510.6667	572.6667
10	705.6667	462.3333	537.3333

Table 2
Peak-to-peak interval for all subjects for funny, fear and sad emotions

SUBJECT	PPI1	PPI2	PPI3
1	146	147.5	151
2	130.5	145.5	138.5
3	168	121	140
4	118.5	100	108
5	128	132	127.5
6	150.5	132.5	116
7	136.5	109	144
8	139	137	124.5
9	130	123	134
10	212.5	167.5	217

Table 3
Area of cardioid pattern for all subjects for funny, fear and sad emotions

SUBJECT	AX	AY	AZ
1	3.98E+04	1.13E+04	6039
2	1.47E+04	564.5	8.06E+03
3	1.06E+04	2642	6.37E+03
4	9.83E+03	1419	3.89E+03
5	1.06E+04	6.69E+03	2.95E+03
6	3.91E+04	2.22E+04	17576
7	35238	7891	8589
8	21470	13039	1.35E+04
9	1.82E+04	5583	12092
10	33441	2.65E+03	9.51E+03

Table 4
Maximum radius of cardioid pattern for all subjects for funny, fear and sad emotions

SUBJECT	M1	M2	M3
1	302.5852	151.9495	175.6786
2	178.3975	42.2306	60.6885
3	187.2933	95.1839	127.5604
4	124.5555	56.9454	54.4472
5	158.9242	138.9544	154.5626
6	306.0547	195.3424	219.0839
7	273.4656	121.8352	140.7403
8	258.5828	211.9098	234.3953
9	192.544	98.3883	108.4313
10	294.277	96.9049	114.8137

To sum it up, the study has concluded that the state of emotions is highly related to the heart's oxygen supply. The heart will absorb more oxygen when the subject is in a happy state making the value for funny state of emotion in tables 1 until 4 appeared higher compared to sad and fear. On another note, when the subject is in fear or sad, the heart absorbs less oxygen. Hence, the value for all classification for fear and sad emotions become smaller compared to funny state of emotion as shown in tables 1 until 4.

III. CONCLUSION

To conclude, this study has thoroughly investigated the capability of PPG in recognizing variability of human's funny, fear and sad emotions. The four covered processes include signal acquisition, pre-processing, feature extraction, as well as decision making. This research considered four classifiers, PPI, maximum amplitude, area and maximum radius of Cardioid loop. Referring to the four classification methods used, this study proposes the first, third and fourth method which are the maximum amplitude, area of Cardioid and the Euclidean distance. The second method however did not contribute well in recognizing the human's emotions.

Taking into consideration the analysis that has been made, this study shows a betterment in emotion detection's system especially in differentiating the funny, fear and sad emotions.

However, rooms for improvements are still needed in order to produce better results when implementing PPG signal to differentiate between funny, fear and sad emotions. Different subjects from different health background as well as group of ages should be put into consideration. Apart from that, researchers might also need to study the behavior or the difference in gender that might influence the results. Moreover, the research might have to record the data when the subject is in normal state so that it can be used as a threshold to differentiate between funny, fear and sad. More methods of classification and analysis can be proposed to enhance the recognition in the future.

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REFERENCES

[1] E. Paul, “Basic Emotions”, in Handbook of Cognition and Emotion, 1st ed., D.T and P.M, ED. San Francisco, CA, USA: John Wiley & Son ltd, PP. 45-60, 1999.

[2] "Health psychology", *Wikipedia*, 2016. [Online]. Available: https://en.wikipedia.org/wiki/Health_psychology.

[3] S. Stephen T, "What Stress Can Do To Your Body | Heart MD Institute - Dr. Stephen Sinatra's Informational Site", *Heart MD Institute - Dr. Stephen Sinatra's Informational Site*, 2009. [Online]. Available: https://heartmdinstitute.com/stress-relief/what-stress-can-do-to-your-body/.

[4] "7 People Die from Stress Every 2 Seconds - Lose Weight, Quit Smoking by Hypnotherapy", *Lose Weight, Quit Smoking by Hypnotherapy*, 2013. [Online]. Available: http://richmondhypnosiscenter.com/2013/04/12/sample-post-two/.

[5] A. Salafi, "Tekanan Punca Bunuh Diri", *Mohd Roslan*, 2009.

[6] M. Mohd Ariff, "Masyarakat Semakin Sedar Kes Dera Kanak-Kanak", *Bernama.com*, 2009.

[7] V. Maria Teresa, B. Juan, L. Pablo, V. Montserrat and B. Raquel, *Human Emotion Recognition Using Heart Rate Variability Analysis with Spectral Bands Based on Respiration*, 1st ed. IEEE, pp. 6134-6137, 2015.

[8] K. Sun, K. Chung, J. Youn, H. Nam, C. Byung and S. Kee, *Neural Network Based Emotion Estimation Using Heart Rate Variability and Skin Resistance*, 1st ed. Korea: Springer-Verlag Berlin Heidelberg, pp. 818-824, 2005.

[9] Y. Sung-Nien and C. Shu-Feng, *Emotion State Identification Based on Heart Rate Variability and Genetic Algorithm*, 1st ed. Taiwan: Ministry of Science and Technology, pp. 538-541, 2015.

[10] P. Min Woo, W. Mincheol, K. Chi Jung and L. Eui Chul, *Individual Emotion Classification between Happiness and Sadness by Analayzing Photoplethysmography and Skin Temperature*, 1st ed. Korea: National Research Foundation of Korea, pp. 190-194, 2013.

[11] L. Yuan-Pin and J. Tzzy-Ping, *Exploring Day-to-Day Variability in EEG-based Emotion Classification*, 1st ed. San Diego, California, USA: Institute for Neural Computation and Institute of Engineering in Medicine, pp. 2226-2229, 2014

[12] M. Elgendi, "On the Analysis of Fingertip Photoplethysmogram Signals", *CCR*, vol. 8, no. 1, pp. 14-25, 2012.

[13] P. Sasi, "Photoplethysmography", *TITAN WELLNESS*, 2015.

[14] Funnyplox. (2013, March 20). Best Babies Laughing Video Compilation 2012. Retrieved from https://www.youtube.com/watch?v=L49VXZwfup8

[15] F. Sanches. (2015, Jan 7). Saw 7 Trailer (Espanol Latino). Retrieved from https://www.youtube.com/watch?v=mgKAYi252qs

[16] Kuliah7MinitK7M. (2016, August 2). Al-Kuliyyah.. Doa Terbaik Untuk Kedua Ibu-bapa.. Ustaz Mohammad Rozie Bin Mohd Rejab. Retrieved from https://www.youtube.com/watch?v=MCo999f2jyw.