Differentiation of Pupillary Signals Using Statistical and Functional Analysis

Areej Babiker[1], Ibrahima Faye[2], Aamir Malik[1]
[1,2]Center for Intelligent Signal and Imaging Research (CISIR)
[1]Department of Electrical and Electronic Engineering, Universiti Teknologi PETRONAS, Malaysia
[2]Department of Fundamental and Applied sciences, Universiti Teknologi PETRONAS, Malaysia

***Abstract*— Emotion recognition nowadays plays vital role in human-computer reaction. Different approaches and methods were applied to recognize accurately individual's emotions. However, pupil diameter (PD) is one of the well-known and reliable approaches in identifying emotions. It is controlled by Automatic Nervous System (ANS) and is easy to detect. The goal of this paper is to identify the difference in PD due to individual's positive and negative emotional states. The paper introduces an experiment conducted to measure dilation in pupil diameter using eye-tracking system during positive and negative emotions. Thirty participants were involved in this experiment and the initial results suggested differences in pupil dilation during negative and positive stimulation at the last seconds of a played sound. It shows more sustained, stable and longer dilation in high arousal negative stimuli. It also discussed functional analysis that is proven to be a useful tool in expressing pupil dilation differences.**

***Index Terms*— pupil signals detection, eye-tracking system, stimulus, functional analysis, positive and negative emotions.**

I. Introduction

Emotions recognition via pupil diameter research has been conducted increasingly in the past 50 years. This is because of the reliability and accuracy shown by such method. Emotion recognition is utilized in many applications. It is used in autonomous video-game characters [1], learning process and tutoring systems [2], affective computing, automatic detectors of affective states including fatigue, depression and stress, smart surveillance systems, call centers, intelligent automobile systems that help ensuring driver safety, mother-infant interaction system, business fields e.g. customer services [3], [4] and lie detector in courts. This led to the explicit variety in emotion recognition systems algorithms and approaches e.g.: (1) the visual from facial images and videos, (2) Kinesthetic from autonomic nervous system (ANS) signals and (3) Auditory from speech [5]. Pupil diameter is found to be optimal in recognizing individual's emotional states and is used in corporate with other physiological signals. Although differences in luminance between stimuli specially in images and videos may have an influence in uncontrolled environment, an important part of the variation in PD was related to differences in emotional content and is confirmed by other signals such as heart rate and EEG signals as in [6].

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Eye movements can provide detailed information of what an individual is considering due to the high ability in considering and discarding various aspects of a task in less than 200ms. Pupil diameter is regulated by the Autonomic Nervous System (ANS) that consist of three divisions: the sympathetic, the parasympathetic and the enteric system [7], [8]. The parasympathetic and sympathetic divisions of ANS govern the two sets of muscles in the iris called the sphincter and dilator papillae, which are responsible of pupil diameter. In some previous studies however, findings and research showed that pupil dilation may indicate emotion, cognitive load or arousal [9] [10], [8], [11], [12] and [13].

Early researches of recognizing emotions started in the last decades. Hess in [10] showed bi-directional papillary change during emotional states. He suggested significant dilation in pupil diameter while viewing pleasant picture and constriction when viewing unpleasant one. Few years later, Woodmansee in [14] reported dilation of subjects who viewed unpleasant scene. Janisse in [15] however, found no evidence of pupil constriction to negative stimuli. In fact, number of recent studies has suggested more dilation in pupil diameter during positive and negative emotions compared to neutral e.g.[8], [11]and [16].

There are recent researches that showed no significant difference between positive and negative emotions e.g. [8] , [17] while other studies as in [18], [19] suggested significant differences between positive and negative emotions. The latter two studies were performed on infants and were examining the effect of peer's emotion on infants' emotional states. In current emotion recognition researches that are related to pupil, one way of analysis is normally used to determine the difference between obtained signals. This is often statistical analysis. However, PD data are signals that change over a function of time. From engineering perspective, it might be useful to address the whole duration of signals to determine differences between positive and negative emotions.

This paper is introducing information obtained from an experimental work with participation of 30 students. The measurement depends solely on the user unconscious behavior represented by autonomic nervous system activity. It has proven to provide rich details on user's emotional states. The experiment was performed to support the hypothesis that negative and positive emotions can be discriminated through pupil diameter. It uses different ways of analysis that is not popular in this field to express signal difference. It describes the database used and stimuli utilized to trigger subject's emotions. It also elaborates on PANAS-X model that was used as self-assessment model.

II. Experimental Phase

An experiment was conducted with the voluntary participation of 30 subjects. This section is divided into 3 parts that explain mainly the subjective data obtained throughout the experiment.

A. Database

The participants of this experiment were Universiti Teknologi PETRONAS (UTP) students whom age range between 20-30 years old. Thirty subjects with normal and corrected-to-normal vision participated voluntarily in this experiment of which 13 were female. A consent form was signed by each subject and brief information about the experiment was given.

Tobii TX300 eye-tracking system was used to detect and record data of PD and eye movement such as eye gaze, fixation and saccades. This system allows large head movement while maintaining the accuracy and precision at a sampling rate of 300Hz, which means recording pupil size every 3.3 msec. Subjects were seated comfortably -in luminance-controlled room- with approximately 65 cm from the eye-tracking system. A five-point calibration was executed before start of the experiment to locate participant pupils. Stimuli were directly delivered through headphones to participant's ear at constant and comfortable level. They were given brief written instructions that were shown also in the system screen prior to the beginning of experiment.

B. Stimulation

Since the emotion detected should be spontaneous, a strong effective stimulation has to be used to ensure the occurrence of desired emotional states. Generally, stimulations are of three types: visual, audio, and audio-visual. In this experiment, audio stimulations were used. Sounds were selected from International Affective Digitized Sounds (IADS) [20]. Audio stimulations were chosen to help controlling the environment of the experiment and thus eliminate the possible effect of luminance on pupil size. Twenty stimuli were used including negative and positive high and low arousing and neutral stimuli and were delivered through headphones directly to participant's ear at a constant and comfortable level.

Sounds were easy to resolve and triggered emotions effectively. They were in different arrangement and not one after the other, to ensure different responses based solely on the stimuli kind. The subjects were exposed to a trial experiment where three practice sounds were heard prior to the experimental ratings (door bell, buzzer and baby sound). This was to provide the subject with rough estimation on the kind of sounds played and to give them chance to practice rating. Each trial included:

- Preparation sound (3 sec).
- Sound stimulus (6 sec)
- Rating interval (21 sec)

The timing and presentation of instruction and stimulations were controlled through computer. Total time of the experiment was almost 12 min with 10.3 min for real experiment plus 1.17 min for examples of presented sounds.

C. Measurement of emotion

Measurement of emotion is the most vexing problem in affective or valence science as suggested by scientific evidence. This is because number of facts are affecting one's emotional status such e.g. subjective experience, physiology, background and behavior. Throughout an extensive review, there were findings from dimensional and discrete perspectives of measurement. Dimensional perspective concentrates mainly on three dimensions, which are Valence, Arousal and Control or Approach avoidance. On the other hand, discrete perspective focuses more on the particular emotion e.g., sadness, surprise, disgust, etc. [21]. However, there are other points of view that divide emotional measurements into three parts, which seem more supported. They are:

- Non-verbal instrument that measures the expressive component of emotion such as: Facial Action Coding System (FACS) of Ekman.
- Verbal instrument or self-report instrument such as Self-Assessment Manikin (SAM) and Positive and Negative Affect Schedule – Expanded form (PANAS-X) model.
- The product emotion measurement instrument (PrEmo) which is non-verbal self-report instrument [22].

Since the relationship between emotion and measurement of this emotion is not well-established [23] and is complicated, self-report data might be considered as a supporting measure. In this experiment we applied verbal instrument represented in Positive and Negative Affect Schedule – Expanded form (PANAS-X) model [24].

PANAS-X model is a simple and easy-to-use model. Most participants completed all the played sounds in the specified time, which was 10 minutes. They were given 20 sec rating interval for each 6-second-played-sound. The model has also 11 discrete emotions. Some of them were considered as basic emotions by psychologists. The model has also 5 scales of rating ranging from very slightly to extremely felt emotions [25].

From the model validation and analysis [24], PANAS-X scales were strongly correlated with the commonly applied measures for state affect. It also indicated that this model scales could be used validly to assess short-term state affect. Through analysis also, three broad subcategories were defined. Fear, Sadness, Guilt and Hostility scales were classified as Basic Negative Emotion. Joviality, self-assurance and Attentiveness were classified as Basic Positive Emotion. Finally Shyness, Fatigue, Surprise and Serenity were grouped as Other Affective States for they do not strongly define either of the aforementioned factors.

Emotions chosen in PANAS model were constructed to be uncorrelated and conforming with the theoretical model supporting the independence of positive and negative affect they normally are [26]. This was made in gray levels color for participants to ease their rating mission. Subjects were asked to rate honestly the sound heard in terms of how it made them feel considering that there is no wrong or right answer. Subjects also were given the choice of neutral in case the stimuli failed to trigger any of their emotions. These facts led to the choice of PANAS-X model as self-report measurement in this experiment.

D. Data Analysis

Data obtained from eye-tracking system were pupil diameter for both eyes, fixation, stimulus onset and offset and a validation code that determines the validity of pupil diameter data. The data provided by the eye-tracking system contains values of both right and left pupils. Both pupils had almost the same behavior in all subjects, p= 0.001 so the average of these values was taken to ease data processing. Then, to determine a baseline for each participant normal pupil diameter, an average of 1sec before stimulus onset was used. Each trial stimulation sound lasted for 6 seconds. Due to the fact that pupil size differs from individual to another based on the iris size, pupil values were then normalized to lie in between [0, 1] to overcome spanning of values in different ranges and to enable proper and accurate signal analysis. After that, moving-average filter using MATLAB was applied to clean data and remove outliers. Missing data were replaced with linear interpolation and trials with over 50% missing data of blinks or artifacts were eliminated. Different way of applying two-tailed paired-sample t-test to measure significant differences between positive and negative emotion is addressed in this paper.

To assess results obtained repeated measures ANOVA was conducted with subject group (Negative and Positive emotions). Multiple comparisons were applied to find out where the differences are, using Bonferroni test. [27]. These analyses were performed using SPSS software with p value = 0.05. Another way of analysis of pupil diameter is used in this paper to aid result analysis. This is called functional analysis, in particular confirmatory type of functional analysis [28]. This is to confirm if our statement about the difference in positive and negative emotions can be confirmed by the data. Since pupil diameter signal represents visible increment during stimulation period, but both timing and dilation differs from participant to another. Thus, the use of functional analysis will help representing the data in a way that assist further analysis and highlight their various characteristics. One simple way of functional analysis for exploring graphically more details about the signal is to use derivatives. This will be explained thoroughly in the next part.

III. Result and Discussion

The experiment was conducted with the mentioned preparation and the analysis was divided into two phases:

- Objective data, which includes data of eye movements and pupil diameter.
- Subjective data that include self-report and the analysis associated with it.

A. Objective data

Using the self-report data, classification was done to group positive emotions together as well as negative emotions. This was supported by the divisions mentioned earlier in measurement of emotion part given by the self-report model utilized. Twenty sounds with pleasure (mean=4.49 and std=1.78) and arousal (mean=5.967, std=1.94) were rated using 11 emotions of PANAS-X model plus neutral status. The participants used numbers that ranged from 1 (very slightly) to 5 (extremely) to rate the sounds based on the felt emotions and chose one emotion only (the strongest) each trial. This might be because of the nature of arousal and valence of the stimuli that depended on the ratings provided with IADS data.

It is worth mentioning that negative emotions like sadness and fear were rated more than hostility and guilt with range of (3 to 1) and positive emotions like joviality and serenity were rated more than self-assurance and attentiveness. The possible explanation is that it is a sign of differences between emotions intensity, preference and processing from an individual to another.

B. Subjective data

Firstly, we noticed no initial decrease in pupil diameter. This is because luminance of the room was controlled and the stimuli used were sounds that has no effect on the pupil like pictures for example [11]. Figure.1 shows the difference of average normalized dilation for positive and negative emotions that depended on PANAS-X model classification.

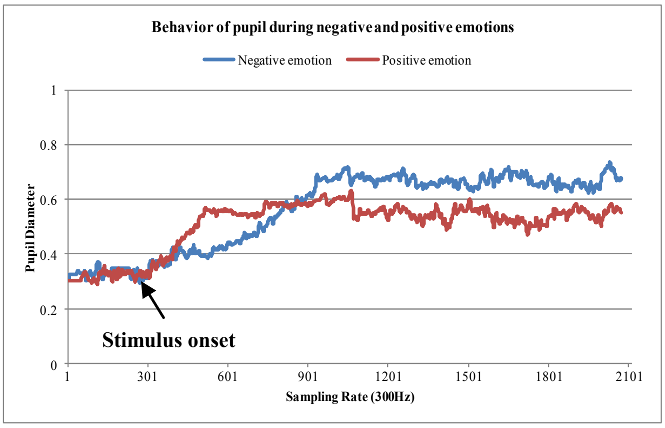

Fig. 1. Pupillary behavior during positive and negative emotions

From Fig.1, one can notice the slower, higher and more sustained dilation of negative trend compared to positive one. Dilation in both cases started almost 1.25sec after stimulus onset and reached the peak almost in 3.2sec after stimulus onset. Highest point in dilation of negative emotions reached 0.73 (normalized value) while in positive ones it was 0.63 (normalized value).

Descriptive statistics was used to find differences between positive and negative emotional signals. The variance, mean and peak differences of the signals were calculated for the six seconds followed stimulus onset as shown in Table.1 below.

Table. 1. Variance, Mean and peak to peak difference of negative and positive signals.

second	Variance	Mean	Peak
Negative signal	0.01	0.59	0.73
Positive signal	0.003	0.53	0.63

From Table.1, small difference was found between the means of positive and negative signals. Variance values indicate that data points tend to be very close to the mean and hence to each others. Negative signal has 130 peaks while positive signal has 135 peaks. Moreover, the peak value of negative signal is higher than the positive one. However, our hypothesis is suggesting significant change in the last two seconds of both signals. Based on this, data were segmented in second's basis to present differences at the end of each second. An average of 300 samples (300Hz sampling rate) was calculated for each participant positive and negative trials. Then t-test was applied and the result is shown in table.2.

Table. 2. T-test result between positive and negative signals.

second	df	h	p
1st sec	-0.6686	0	0.5091
2nd sec	-0.1815	0	0.8572
3rd sec	2.1587	1	0.0393
4th sec	1.2837	0	0.2094
5th sec	0.0172	1	0.0344
6th sec	2.4394	1	0.0211

In Table.2, h indicates the result for t-test. When h=1 null hypothesis can be rejected at the 5% significance level while h=0 indicates a failure to reject the null hypothesis. The value of p determines the test significant level which is by default in MATLAB is 0.05 or 5% significant level and df represents the degree of freedom. It is founded that initial dilation (3rd second) besides sustainability of dilation (5th and 6th second) are considered differences between positive and negative emotions. This is indicated by the significant value of P that is less than 0.05. Repeated measures ANOVA was applied to check and confirm the significance of difference as well. Since data violated sphericity assumption, Greenhouse_Geosser test was used [29]. The difference was significant in 3rd , 5th and 6th second and thus confirmed the result of t-test. However, the mean differences of Bonferroni correction test was 0.286 that shows pupil diameter during negative stimuli was higher and significantly differs in mean compared to pupil diameter during positive stimuli. The other way of analysis used is the functional analysis. The 1st step that should be taking when performing the sort of analysis is signal smoothing. Figure.2 shows the smoothed signals of Fig.1 using moving average filter.

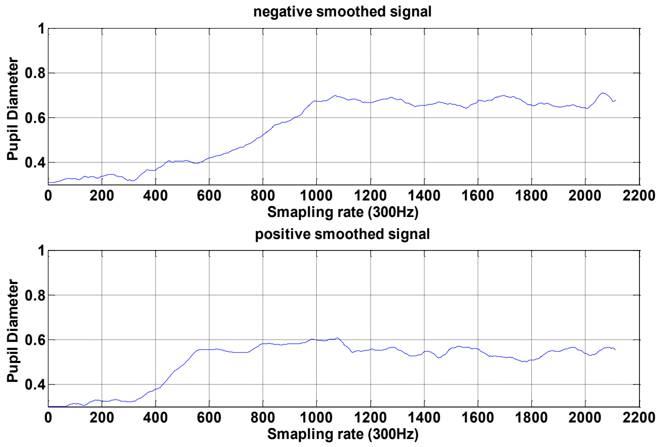

Fig. 2. Smoothed Positive and Negative Signals.

Next step was to get the derivative of both signals and compare them. This is shown in Fig.3 and Fig.4

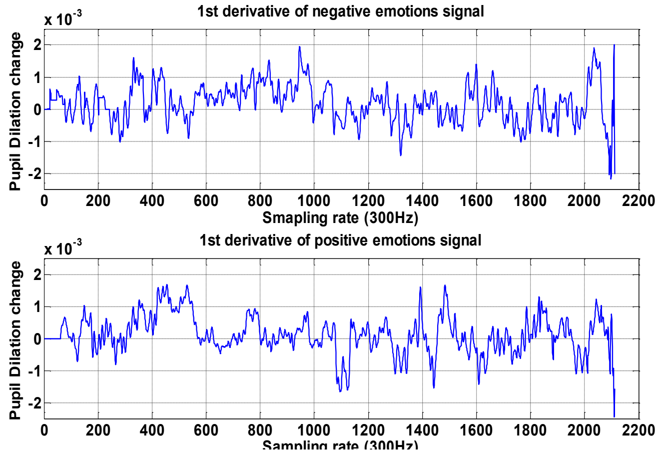

Fig. 3. 1st Derivative of both Negative and Positive signals

In the above figure, the first graph shows negative emotion signal behavior. As can be seen, the highest point occurred around 1000 indicating big change occurring at this point. From the signal behavior shown in Fig.2, one can till the cause for this change by observing the difference between point 600 in positive signal and point 1000 in negative signal of Fig.3. This is where the difference was significant using t-test and repeated measures ANOVA (Table.2). After that, almost sustained dilation in negative signal occurred and this is shown by low peaks amplitude till point 1600 when few changes occurred. On the other graph that shows positive signal behavior, highest point of peaks' amplitude occurred at around point 500 and from the original signal shown in Fig.2 this is the dilation point for this signal. Dilation sustained for a while and started decaying at around point 1100 and this is indicated by the very low peak shown in Fig.3. Then, low and high peaks continued to occur till point 1600 and continued after that, indicating change in the original signal. Figure.4 below shows both signals on single plot.

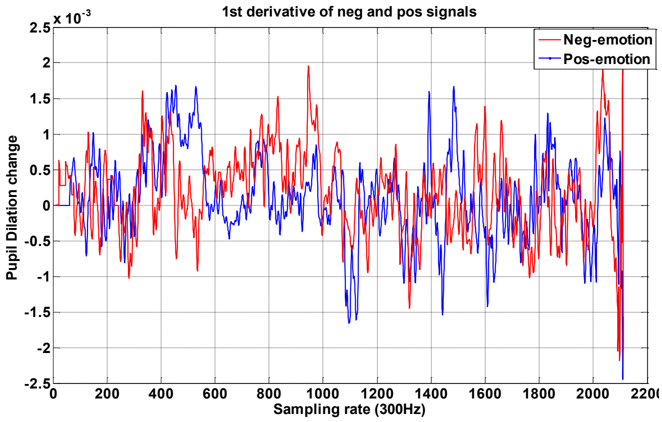

Fig. 4. Comparison between both Signals Derivatives.

Final stage was to plot the differences between the two signals and this is shown in Fig.5. From this figure, there are three points were high change occurred. These were between 1) point 400 and 600 2) between 1000 and 1200 and 3) between 1400 and 1600.

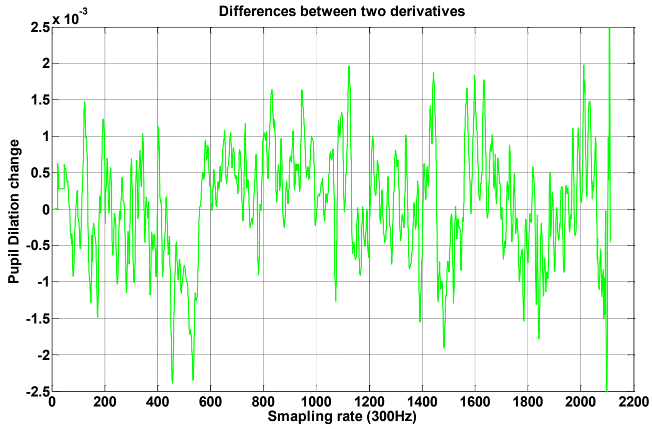

Fig. 5. Difference Signal between the Two Derivatives

At the first point, a negative peak occurred indicating that positive signal was higher than negative one and this is where the dilation of positive emotion effected the pupil. In the other point the difference was positive indicating higher negative emotion and this is where change occurred on pupil diameter due to negative stimuli. At last point, more positive peaks occurred compared to negative ones and they were a bit less than the previous peak indicating differences between positive and negative signals. These result support the statement that positive and negative emotions have different effect on pupil diameter while both dilate.

Numerous researchers tried studying the difference in papillary change between emotions in general. Though, few researches addressed directly positive and negative emotions differences, it is predicted that strong negative and positive emotions show higher dilation than normal or neutral ones [11], [8]. This was supported by the objective and subjective data used in this experiment.

Moreover, one may argue that increase in pupil diameter might be affected by the intensity of the sounds and that loud sounds will cause large dilation. It has been addressed in previous studies as in [30] and its shown that loud sounds cause a slight and negligible increase in pupil diameter of about 0.04mm. In our study, dilation of pupil diameter reaches 0.45mm in some cases of the negative stimuli indicating that the result is less likely to be due to sound tone or intensity.

IV. Conclusion

This paper is supporting the use of pupil size variation as an index for individual's emotional states and is presenting and evidence for differences between negative and positive emotions effect on individuals' pupil diameter. It examined thoroughly experimental phase in terms of stimuli, dataset and type of emotion measurement used. The paper also supported the hypothesis that pupil dilates with emotional states regardless of whether it is positive or negative emotions. Results obtained with statistical tools and functional analysis representation showed significant difference between negative and positive emotions in terms of sustainability and dilation diameter.

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