

Emotion Recognition using Parabolic Phase Space Mapping for Heart Rate Variability Analysis

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Abstract

In this paper, extracted features from Parabolic Phase Space Mapping (PPSM) of RR time series and its extended version were used to distinguish four emotion states (energetic, calm, happy, and anxious) induced by picture stimuli. In order to induce emotions, four groups of pictures with different emotional concepts were used as a visual stimulus while the lead II of ECG was recorded. Induced emotion was confirmed by self-assessment manikin test. The results show that extracted features were significantly different between energetic and calm, energetic and happy, energetic and anxious, calm and happy, calm and anxious, and happy and anxious ($p < 0.05$).

1. Introduction

A mental state that arises spontaneously rather than through conscious effort is called emotion [1] and is often accompanied by physiological changes. It is shown that one approach for evaluating physiological response to emotions is heart rate variability (HRV) analysis [1, 2]. HRV is responsible for representing the changes on automatic nervous system (ANS), especially in the activation and deactivation of sympathetic and parasympathetic systems.

The people explain their emotions differently, so we have to have scales for measuring and labeling different emotions in different people [3] which are valence and arousal [4]. Valence represents the pleasantness of stimuli, with positive (or pleasant) at one end and negative (or unpleasant) at the other [4]. Another dimension is arousal (activation level). Researches shown that some emotions can be distinguished depending on their arousal and valence level [3, 4]. In this study, the arousal and valence

dimension of SAM test were used to estimate emotions which are induced by visual stimuli using 2D model of emotions.

Furthermore, HRV analysis using the nonlinear maps (Parabolic Phase Space Mapping (PPSM) and its extended version) was used for studying physiological response to different emotions. The PPSM can highlight subtle changes in RR time series and was successfully used for arrhythmia detection [5, 6].

2. Method and Material

In this paper, pictures were used for emotion induction. Self-assessment manikin (SAM) test and 2D model of emotions were used to capture induce emotion. Then, the relation between induced emotions and its physiological response was analyzed by the HRV analysis using the novel Parabolic Phase Space Mapping (PPSM) and the extended novel features (Figure 1).

2.1. Participants and Protocol

In order to induce four different emotions (energetic, calm, happy, and anxious), four groups of pictures with four different emotional concepts from the international affective picture system (IAPS) [7] were used as a visual stimulus, four pictures in each group. ECG (Lead II with sampling frequency: 200Hz) was recorded from 20 healthy males as subjects (Age: 25.04 ± 0.87) they were watching each group of pictures (each group was shown for five minutes). ECG data was recorded while participants were seated in a chair in front of a computer monitor and were watching stimuli pictures (presented for five minutes each group). A 10 minutes break was given between each picture stimuli to cancel the effects of previous stimulation. In order to label the emotion state which was induced by

each picture group, SAM test was used before the break to measure the valence and arousal level of each emotion.

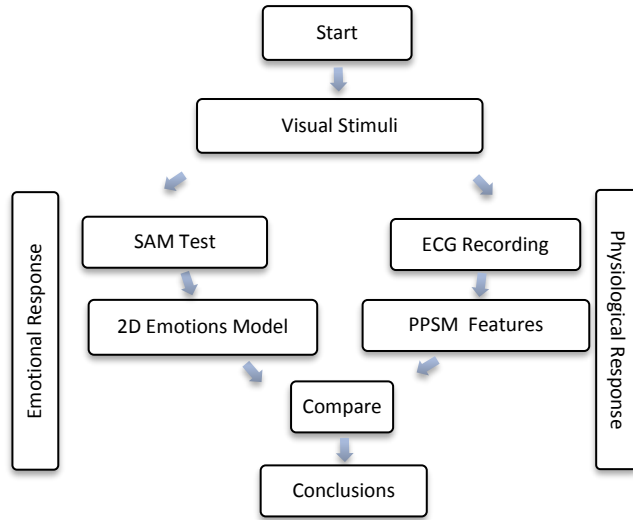


Figure 1. Capturing emotional response to visual stimuli using physiological response.

2.2. Self-Assessment Manikin Test

After each stimulus, the subjects answered the SAM test. SAM test consists of a series of pictograms to judge the affective quality of stimuli by arousal and valence level.

As shown in Figure 2, the SAM figures range from frowning, unhappy to smiling, happy, on the valence dimension [8]. For the arousal dimension, the figures range from relaxed, sleepy to excited and wide-eyed [8]. The subject can select any of the five figures comprising each scale (-2, -1, 0, +1, +2).

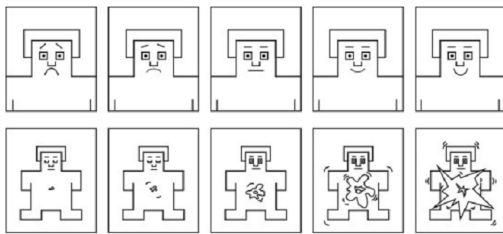


Figure 2. Self- Assessment Manikins (SAM) test

2.3. 2D Model of Emotions

As mentioned in previous section, every emotion is defined by two dimensions Arousal and Valence. By plotting arousal versus valence, a 2D emotion model as it is shown in Figure 3 will be constructed. This model

provides a simplified representation of human emotions by two dimensions (arousal and valence) [9].

In this study, we have considered four groups of emotions that are energetic, calm, happy, and anxious.

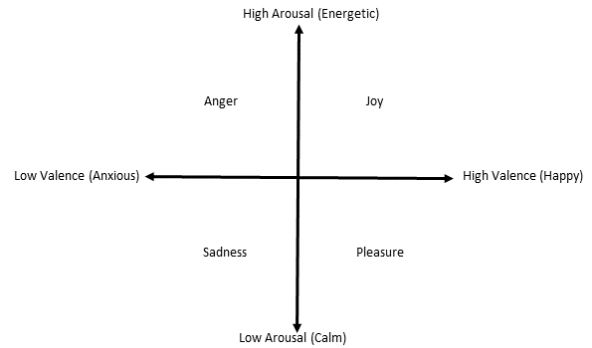


Figure 3. 2D model of emotions

2.4. HRV Analysis

For QRS detection, Pan–Tompkins algorithm [10] following by manual inspection was employed. Extracted QRS peaks were used for creating RR intervals.

2.4.1. Parabolic Phase Space Mapping (PPSM)

For discriminating heart arrhythmia, Jafarnia Dabanloo et al. introduced a Parabolic Phase space Mapping (PPSM) for analysis of RR intervals [6].

Using RR time series $(RR_1, RR_2, \dots, RR_n, RR_{n+1})$, input to PPSM will be created using the following equations:

$$x = \{x_1, x_2, \dots, x_n\} = \{RR_1, RR_2, \dots, RR_n\} \quad (1)$$

$$y = \{y_1, y_2, \dots, y_n\} = \{RR_2, RR_3, \dots, RR_{n+1}\} \quad (2)$$

Where n is the number of points in the map which is one less than the length of the RR time series [6, 11]. PPSM consists of all the ordered pairs:

$$(x_i, (\overline{RR} - y_i)^2) \quad (3)$$

in which $i= 1,2,3, \dots, n$ [6]. \overline{RR} is average of RR intervals defined as:

$$mean(RR) = \overline{RR} = \frac{1}{n+1} \sum_{i=1}^{n+1} RR_i \quad (4)$$

By evaluating the distribution of points in PPSM which is shown in Fig. 4, Jafarnia Dabanloo et al. could estimate a two degree polynomial equation in the form of $Y = Ax^2+Bx+C$, in which [6]:

$$Y = (\overline{RR} - y_i)^2 \quad (5)$$

The coefficients of the estimated polynomial (A , B , and C) fit the point distribution in *PSPM* were extracted as features for representing this map [6].

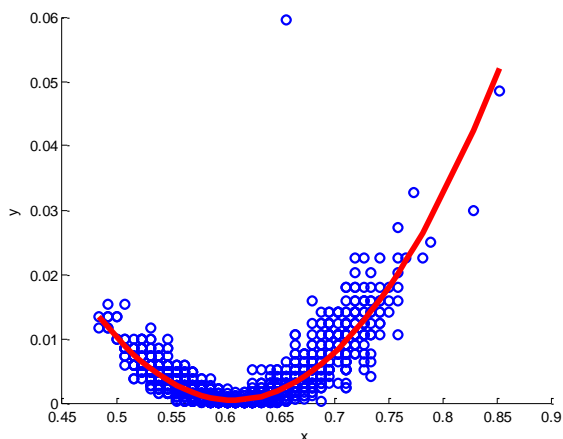


Figure 4. Points' distribution in *PSPM* and the estimation of a quadratic equation.

2.4.2. Extended Parabolic Phase Space Mapping (EPPSM)

In EPPSM, new features are extracted based on the location of point's distribution relative to the estimated polynomial. Using the following equations, the points will be categorized as a) points which are above the curve (A), b) points which are on the curve (O), and c) points which are below the curve (B) (figure 5):

$$\begin{aligned} \text{If } (y - Ax^2 - Bx - C) < 0 &\Rightarrow p_i \in B \\ \text{If } (y - Ax^2 - Bx - C) = 0 &\Rightarrow p_i \in O \quad (6) \\ \text{If } (y - Ax^2 - Bx - C) > 0 &\Rightarrow p_i \in A \end{aligned}$$

In which $p_i(x_i, y_i)$ is each point in the mapping and $i = 1, 2, \dots, n$.

Compared to *PSPM*, location of points relative to estimated polynomial will be marked by color in EPPSM (blue, red, and green shows that a point is above, on, and below estimated polynomial, respectively), Figure 5. After finding the classes of all the points, number of points in each class was considered as features in EPPSM (N_B , N_O , and N_A). N_B is the number of points in class B that means the number of points which are below the curve, N_O is the number of points in class O that means the number of points which are on the estimated curve, and N_A is the number of points in class A that means the number of points which are above the estimated curve.

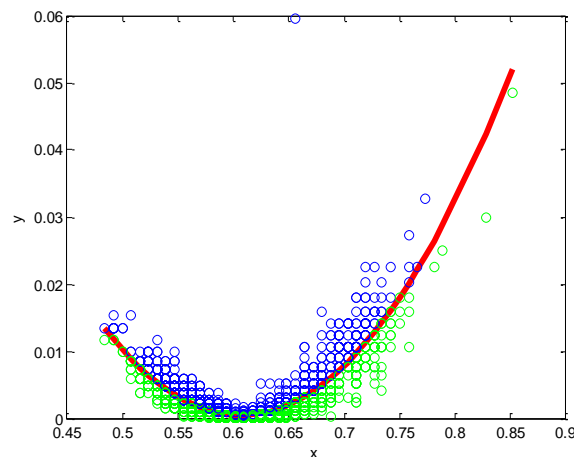


Figure 5. Points in *PSPM* are color coded based on their position relative to the estimated polynomial.

2.5. Statistical Analysis

All continuous features were reported as mean \pm standard deviation. In this study, Kruskal-Wallis test was used to compare proposed features across different emotion groups while significant statistical level was set to 0.05.

3. Results

Means and standard deviations of extracted features across four emotion groups have been reported in Table 1. The p -values obtained from Kruskal-Wallis analysis are summarized in Table 2 and Table 3 for all six extracted features across different emotion groups.

There were a significant differences in A between energetic and happy (p -value $<$ 0.05) and between happy and anxious (p -value $<$ 0.05). Furthermore, feature C was only significantly different between calm and anxious. In features extracted from EPPSM, N_B was significantly different between energetic and calm, calm and happy, and calm and anxious (p -value $<$ 0.05). Also, N_A was significantly different between energetic and calm, energetic and happy, energetic and anxious, calm and happy, calm and anxious, and happy and anxious (p -value $<$ 0.01).

Table 1. Means and standard deviations of extracted features across four groups of emotions

	Emotions			
	Energetic	Calm	Happy	Anxious
A	0.57 ± 0.38	-0.01 ± 0.11	0.05 ± 0.17	0.26 ± 0.14
B	-0.80 ± 0.56	-0.63 ± 0.99	-2.95 ± 9.28	-0.47 ± 0.31
C	0.29 ± 0.21	2.28 ± 8.26	32.99 ± 119.72	0.23 ± 0.19
N_B	2478 ± 457	53 ± 87	2255 ± 202	2316 ± 319
N_O	0 ± 0	0 ± 0	0 ± 0	0 ± 0
N_A	1148 ± 457	2 ± 4	136 ± 202	842 ± 319

Table 2. *P*-value for PPSM features across different emotion groups (values in bold indicate significant differences, *p*-value<0.05).

Groups	PPSM Features		
	A	B	C
Energetic & Calm	0.82	0.26	0.07
Energetic & Happy	<0.05	0.19	0.19
Energetic & Anxious	0.05	0.07	0.19
Calm & Happy	0.06	0.13	0.08
Calm & Anxious	0.60	0.11	<0.05
Happy & Anxious	<0.05	0.96	0.16

Table 3. *P*-value for EPPSM Features across different emotion groups (values in bold indicate significant differences, *p*-value<0.05).

Groups	EPPSM Features		
	N_B	N_O	N_A
Energetic & Calm	<0.05	-	<0.05
Energetic & Happy	0.39	-	<0.05
Energetic & Anxious	0.56	-	0.01
Calm & Happy	<0.05	-	<0.05
Calm & Anxious	<0.05	-	<0.05
Happy & Anxious	0.78	-	<0.05

4. Discussion

In this paper, parabolic phase space mapping and its extended version were created using RR intervals. Extracted features from these two mappings were significantly different between four emotional states induced by standardize pictures stimuli. Results suggests that HRV analysis using these mappings and associated parameters can capture changes in physiological response to emotion induced by pictures stimuli.

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