

A New Representation of Emotion in Affective Computing

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Keywords: Emotion, Affective Space, Polar Coordinate System

Abstract. In the recent years, increasing attention has been paid to the area of affective computing, which deals with the complex phenomenon of human emotion. Therefore, a model for describing, structuring, and categorizing emotional states of users is required. The dimensional emotion theory is one of widely used theoretical foundations for categorization of emotions. According to the dimensional theory, emotional states are projected to the affective space, which has two dimensions: valence and arousal. In order to navigate in the affective space, Cartesian coordinate system is used, where emotion quality is defined by combination of valence and arousal. In this paper, we propose another representation of the affective space with polar coordinate system. The key advantages of such a representation include (1) capability to account not only for emotion quality, but also for emotion intensity, (2) reasonable explanation of the location of neutral emotion in the affective space, and (3) straightforward interpretation of the meaning of an emotional state (quality defined by angle and intensity defined by distance from the origin). Although in our experiment most of the induced emotions can be differentiated with polar coordinate system, further investigation is still needed to find out either Cartesian or polar coordinates system represents affective space better in practice.

Introduction

The dimensional emotion theory is based on the idea of a reduction of complex multidimensional phenomenon to more simple representation [1], which involves a low number of meaningful dimensions. The most common variation of the dimensional theory involves the dimensions of arousal and valence, and, therefore, creates a two-dimensional affective space [2]. The dimensional emotion theory is popular among researchers and is used in many applications, such as [3].

However, relying exclusively on the valence and arousal dimensions to describe emotional state seems insufficient to represent an important aspect of emotion, namely the intensity. Traditionally the fact that emotion can vary in intensity received surprisingly little reflection in theories of emotion. Frijda et al. pointed out in [4] that the intensity is one of the most salient features of emotion and one cannot talk about emotion without talking about emotion intensity. These considerations trigger a question how the intensity of emotion can be reflected in the affective space. According to Russell [5], the circular ordering of emotions in the affective space can complement the dimensional representation and the distance from an emotional state to the origin of the space can be interpreted as the intensity of emotion. Therefore, it might be reasonable to use polar coordinate system to navigate in the affective space.

Aims of the Present Study

Although polar coordinate system was already applied earlier [6], the majority of researches preferred to use Cartesian coordinate system to determine the positions of emotions within the affective space. The horizontal axis (X) was commonly used to represent valence and the vertical one (Y) was used for arousal. The intersection of the axes was considered to be the point of origin and represent a kind of neutral emotional state. However, such an approach is questionable for several reasons. First, it does not offer a convenient way to account for emotion intensity. Second, according to the dimensional theory the origin represents the neutral emotional state. However, based on the experimental data from the previous research [7], the neutral emotional state is not precisely located in the origin of the affective space. These observations challenge the statement that the origin represents neutral state. Moreover, they question where in the affective space the origin should be located and what the meaning of the neutral emotional state is. In our study, we investigate whether an introduction of a new way to represent the affective space might solve the issues mentioned above.

Approach

There are two widely used coordinate systems for two-dimensional spaces: Cartesian and polar. Each of them allows an unambiguous identification of a point in 2D space, but there are tasks, which can be easier solved in Cartesian coordinates system than in polar, and vice versa. A good example of such a task is the equation of a circle centered at the origin that is more simple and elegant in polar rather than in Cartesian coordinate system.

Our hypothesis, which we want to put forward in the present paper, is that although the affective space is usually described with Cartesian coordinate system, it might be more appropriate and advantageous to navigate the affective space with polar coordinate system. To the best of our knowledge it was first proposed by Russell [5] that emotional states in the affective space can be distinguished with angle in polar coordinate system. Moreover, he suggested that neutral emotional states would fall near the origin of the affective space, while the states with strong intensity would be located further from the origin. Therefore, the distance between the origin and an affective state is interpreted as emotion intensity. Similar ideas can be found in the work of Reisenzein [8], who argued that dimensional theory should account for emotion quality and emotion intensity because otherwise a theory cannot be regarded as an adequate theory of the structure of emotional experience. Reisenzein used Cartesian coordinate system and proposed that emotion quality is defined by the proportion of valence and arousal and emotion intensity is defined by absolute values of valence and arousal [8]. In polar coordinate system this would mean that quality of emotion is defined by angle, and emotion intensity is defined by radius.

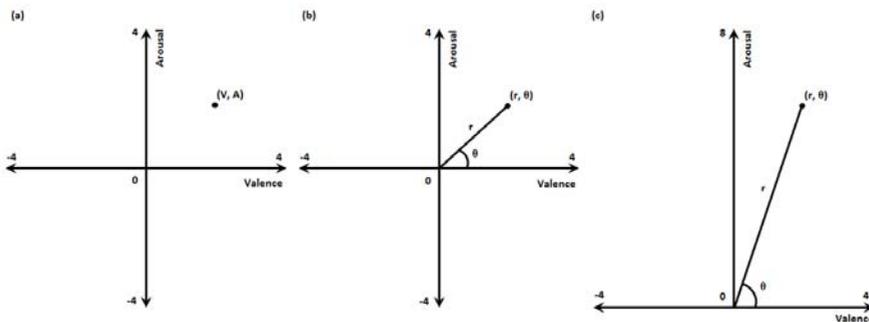


Fig. 1 Representations of the affective space: Cartesian (a), polar (b), and modified polar coordinate systems (c). A dot in the affective space corresponds to a particular emotional state.

However, there is a difficulty associated with the representation of the emotional states in polar coordinate system, which is determined by the fact that rules of linear statistics do not apply for circular data. Consider the following two angles as an example: 2° and 358° . If we operate in a linear

space, then calculating the mean of these angles would result in an angle of 180°. However, it is obvious that the result is wrong and the correct mean angle is 0°. This example illustrates the fundamental difference between linear and circular statistics [9]. Unfortunately, only few statistical software packages support analysis of circular data, and it might be an obstacle for adopting the representation of the affective space with polar coordinate system. Furthermore, in polar coordinate system we faced the problem of interpretation of the emotional states that are located close to the origin of the coordinate system. It was unclear what quality (defined by angle) of emotion with zero intensity (defined by distance) is, because in polar coordinate system a point with zero distance from the origin can have arbitrary angle.

Taking the above-mentioned issues into account, we transformed the dimension of arousal by adding 4 to the original values. The modified coordinate system has now the origin located at the (-4) end of the old dimension of arousal (as shown on Figure 1(c)). The obvious benefit of this modification is that it avoids the difficulty with the statistical analysis of circular data, because in modified polar coordinate system angle can vary only between 0° and 180°, and, for this reason, linear statistics can be used. Moreover, the representation of the affective space with modified polar coordinate system solves the problem of interpretation of emotional states with zero intensity, because they can be assumed to have quality (defined by angle) of ‘neutral’ emotion. The validity of the modified polar system needs an investigation. In order to address the questions highlighted above we designed an experiment with the data from International Affective Picture System (IAPS) [10]. The results will be mapped into the affective space as shown on Figure 1 (a, c) and the representations will be evaluated with the aim to identify which of them is supported by empirical data as the most suitable representation of emotion.

Experiment

According to the previous study that applied IAPS [10], the stimuli in these databases are generally clustered into four categories: Positive-Arousing, Positive-Relaxing, Neutral, and Negative. IAPS contains sufficient amount of visual stimuli, including 1194 pictures. For our experiment we selected six stimuli for each category (24 pictures in total) from the original pool of stimuli that are contained in this database. Our study followed the method used by IAPS, utilizing the Self-Assessment Manikin (SAM) [11] as a measuring tool for participants to consciously report their emotion. SAM captures two dimensions of an emotional state: valence and arousal. The selected stimuli were presented to participants on a computer screen and their self-assessment ratings for every stimulus were collected via a web-based interface.

For our experiment, 37 healthy participants, including 17 males and 20 females, were recruited with payment of 9 euros. The participants had diverse nationalities: 17 from Asia, nine from Europe, eight from Middle East, and three from South America. Participants in this study had a mean age of 26 years and nine months, ranging from 18 to 50 years (one under 20 years old, two above 40 years old).

Table 1. An overview of the stimuli used in the experiment, including five categories: Positive-Arousing (PA), Positive-Relaxing (PR), Neutral (NT), and Negative (NG).

Category	Stimuli (Code Number)
PA	Erotic (4652), Erotic (4668), Cupcakes (7405), Sailing (8080), Bungee (8179), RollerCoaster (8490)
PR	Butterfly (1605), Rabbit (1610), Baby (2060), NeutBaby (2260), Nature (5760), Clouds (5891)
NT	Mushroom (5530), RollinPin (7000), HairDrier (7050), Book (7090), Lamp (7175), Cabinet (7705)
NG	BurnVictim (3053), BabyTumor (3170), AimedGun (6230), Attack (6350), Vomit (9321), Dead (9412)

The experiment was set up with a web-based system for presentation of stimuli and the experimental data were stored in a database for further analysis. The experiment followed

within-subjects design. Every participant went through the same set of stimuli (see Table 1). Before the start of the experiment, each participant completed a tutorial to get familiar with the controls and the interface. Once the experiment session began, the screen started to display pictures one at a time in a random order. Each picture was exposed to a participant for six seconds. Then the interface paused for five seconds. The SAM scaled were shown after the pause. Participants had unlimited time to report their emotional feelings. Another 5-second pause appeared after the self-report, which was meant to let participants calm down and recover from the previously induced emotion. Then the next picture was shown. All of the 37 participants ran through the whole procedure individually.

Results

Multivariate analysis of variance for repeated measurements, which we conducted with two coordinate systems, demonstrated that there is a significant main effect of the category of stimuli on the self-assessment ratings provided by participants (Cartesian: $F(6,31) = 98.742, p < 0.001$; modified polar: $F(6,31) = 105.595, p < 0.001$). Moreover, inference tests of within-subject contrasts among all of the four categories were performed in two coordinate systems using univariate analysis of variance. The mean values of the self-assessment ratings for every category are plotted in the affective space with both Cartesian and modified polar coordinate systems at Figure 2.

Table 2. Inferential statistics of the self-assessment ratings in the affective space using Cartesian and modified polar coordinate systems for every category (Positive-Relaxing (PR), Positive-Arousing (PA), Neutral (NT), and Negative (NG)) is shown. ΔM indicates the difference in the mean values of two categories (category 1 (C1) minus category 2 (C2)); p value shows the results of the tests of within-subject contrasts on ratings among each category in two different representations (Cartesian and modified polar).

Attributes	Cartesian				Modified polar			
	C1 \ C2	PA	NT	NG	PA	NT	NG	
Valence	PR	$\Delta M = 0.77$ $p < 0.001$ ***	$\Delta M = 1.648$ $p < 0.001$ ***	$\Delta M = 5.045$ $p < 0.001$ ***	Distance	$\Delta M = -1.548$ $p < 0.001$ ***	$\Delta M = 0.635$ $p = 0.016$ *	$\Delta M = -2.266$ $p < 0.001$ ***
	PA	-	$\Delta M = 0.878$ $p < 0.001$ ***	$\Delta M = 4.275$ $p < 0.001$ ***		-	$\Delta M = 2.183$ $p < 0.001$ ***	$\Delta M = -0.718$ $p = 0.001$ ***
	NT	-	-	$\Delta M = 3.397$ $p < 0.001$ ***		-	-	$\Delta M = -2.901$ $p < 0.001$ ***
Arousal	PR	$\Delta M = -2.356$ $p < 0.001$ ***	$\Delta M = -0.262$ $p = 0.381$	$\Delta M = -2.744$ $p < 0.001$ ***	Angle	$\Delta M = -24.923$ $p < 0.001$ ***	$\Delta M = -29.493$ $p < 0.001$ ***	$\Delta M = -67.376$ $p < 0.001$ ***
	PA	-	$\Delta M = 2.094$ $p < 0.001$ ***	$\Delta M = -0.388$ $p = 0.103$		-	$\Delta M = -4.57$ $p = 0.154$	$\Delta M = -42.453$ $p < 0.001$ ***
	NT	-	-	$\Delta M = -2.482$ $p < 0.001$ ***		-	-	$\Delta M = -37.883$ $p < 0.001$ ***

(* represents p value < 0.05, which shows significance; ** represents p value <= 0.01, which shows high significance; *** represents p value <= 0.001, which shows very high significance.)

According to the experimental data presented in Table 2, most of the categories of stimuli can be differentiated by the valence ratings using Cartesian coordinate system. Only the arousal ratings of Positive-Relaxing and Neutral as well as of Positive-Arousing and Negative categories are not significantly different in Cartesian coordinate system. In modified polar coordinate system the angles of Positive-Arousing and Neutral categories were not significantly different. Other categories could be distinguished by angle in modified polar coordinate system. The distance from the origin in modified polar coordinate system successfully allowed differentiation between all the categories.

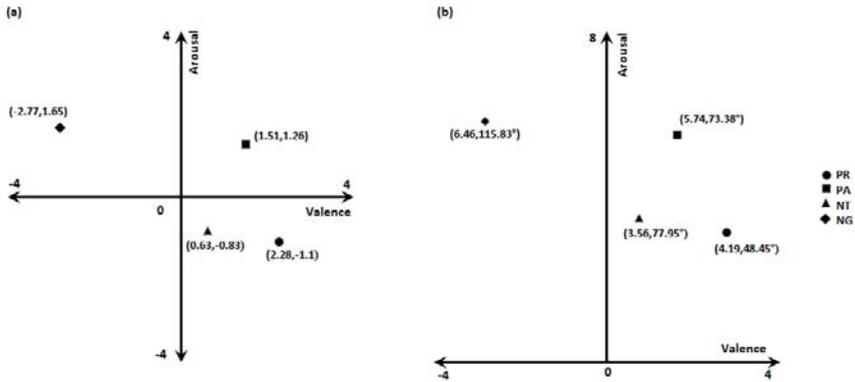


Fig. 2. Four categories (Positive-Relaxing (PR), Positive-Arousing (PA), Neutral (NT), and Negative (NG)) of the stimuli are plotted in the affective space with Cartesian (a) and modified polar (b) coordinate systems.

Discussion

Based on the analysis of the data presented in Cartesian coordinate system, the differences between the four categories of stimuli are significant and their positions in the affective space are consistent with the previous research [10, 11]. Therefore, a conclusion can be drawn that the experimental materials and design are valid. In order to answer the research questions, we compared the representations of the affective space with Cartesian and polar coordinate systems. As it can be seen from Table 2, modified polar coordinate system has one non-significant effect among all categories, whereas Cartesian coordinate system has two. Although this data implies that modified polar coordinate system better describes the affective space, this advantage is not as clear as we expected. Nevertheless, the representation of the affective space with polar coordinate system (modified or non-modified) provides an additional benefit of the capability to define emotion quality and emotion intensity in a straightforward manner. However, in the previous sections a modified configuration of polar coordinate system with the transformed dimension of arousal was introduced for the following reasons.

First, we encountered the above-mentioned problem of arbitrary values of an angle that corresponds to emotional states with zero intensity. For instance, it is unclear what emotion quality should have emotion with zero intensity. Should it have quality of the corresponding emotion or neutral quality? If the first assumption is correct, then it is necessary to know the angle, which defines the emotion quality; however, the angle cannot be computed, because the emotional state is located in the origin. On the other hand, if the second assumption is correct, there is a contradiction between locations of the neutral emotional state (see Figure 2(a)) and the emotional states with zero intensity. According to the empirical data, neutral emotions are not located in the origin of the affective space and have certain emotion quality and intensity. For this reason it is not very plausible to treat emotional states with zero intensity as ‘neutral’ emotion.

Second, intuitive considerations seem to challenge the concept of negative arousal. Indeed, it seems to be plausible that there are emotional states with high, medium or low arousal and theoretically with zero arousal as well, but it is not clear how arousal can be negative and what is the meaning of negative arousal. Moreover, the literature in this field also suggests that arousal does not have negative values [12]. Therefore, from our point of view, the configuration of the affective space should only contain non-negative values of arousal.

Analysis of the experimental data presented in modified polar coordinate systems revealed that all four categories of stimuli, except the pair of Positive-Arousing and Neutral, can be distinguished one

from another by angle. It is not clear why these two categories have the same emotion quality and this question should be further investigated. Overall, the modified polar coordinate system enabled us to distinguish every category of stimuli by angle and thus justified the usefulness of the idea to transform the dimension of arousal.

Conclusion

Affective computing applications require a model for structuring and categorization of emotional states. As it was discussed above, the dimensional emotion theory is so far one of the most widely used theoretical foundations for description of emotion. In the dimensional theory emotional states are mapped to the affective space, which has the two dimensions of valence and arousal, using Cartesian coordinate system. According to our experimental data, polar coordinate system is also capable of representing the affective space and, in fact, is more suitable for this purpose than Cartesian coordinate system, because emotion quality and emotion intensity can be naturally expressed with angle and distance from the origin. However, in order to have meaningful and convenient for statistical analysis representation of emotion quality and emotion intensity, the origin of polar coordinate system should be redefined via the dimension of arousal with only non-negative values. Despite of the first promising results it is still unclear whether modified polar coordinate system is superior to Cartesian coordinate system, and, therefore, further research with larger sets of emotional stimuli is required to validate it.

Acknowledgments This work was supported by the Erasmus Mundus Joint Doctorate (EMJD) in Interactive and Cognitive Environments (ICE), which is funded by Erasmus Mundus of the European Commission under EMJD ICE FPA n 2010-2012.

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