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Two dimensional affective state distribution of the brain under emotion stimuli

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Abstract— **Emotions are ambiguous. Many techniques have been employed to perform emotion prediction and to understand emotional elicitations. Brain signals measured using *electroencephalogram* (EEG) are also used in studies about emotions. Using KDE as feature extraction technique and MLP for performing supervised learning on the brain signals. It has shown that all channels in EEG can capture emotional experience. In addition it was also indicated that emotions are dynamic as represented by the level of valence and the intensity of arousal. Such findings are useful in biomedical studies, especially in dealing with emotional disorders which can results in using a two-channel EEG device for neurofeedback applications.**

I. INTRODUCTION

Studies of emotions had been widely viewed as being traditionally researched in psychology discipline. According to theories of basic emotions, emotions are categorical, in such a way that each basic emotion is governed by a unique and independent neural system. On the other hand, from the dimensional perspective, a set of neural systems are posited to regulate all different emotions. Many schemes are proposed based on categorical and dimensional views.

However, a study rooted from the dimensional approach has produced a prominent scheme for quantifying emotions, known as a circumplex model of affect. The model is also well-known as an Affective Space Model (ASM). For a prominent 2-dimensional space model, an emotion is mapped on the space model based on values of valence and arousal. This model has been used to measure emotions from different input modalities. With the emergence of neuroimaging techniques, signals produced by electrical currents during brain activities can also be captured and processed as the inputs to derive valence and arousal values for measuring emotions using ASM.

Although many studies have been conducted to investigate specific neural circuits for different emotions, the findings do not reconcile to the same consensus [1] [2]. For example, in [3], *mesolimbic* network is suggested to be the neural pathway for pleasure sensation and *reticular* network is postulated to be the pathways for arousal. However, in a different study [4], under a higher microscopic resolution, brain circuits subserving valence and arousal were determined. The main objective of this study is two-fold: (1) to use EEG for detecting areas of human brain which are activated through different emotional elicitations, and (2) to observe the dynamic of emotions representing by valence and arousal values in EEG signals during emotional experiences.

A. Theories of Emotions

1) Basic emotions

A major theory of emotions proposed that humans are instilled with a set of *basic emotions*. Each of the emotions is different than other emotions as perceived from psychological and physiological manifestations. Over the years, different researchers have come up with different lists of basic emotions, as discussed in [5],[6],[7] and [8].

Human brain, as viewed as a *triune architecture*, is divided into three strata of evolutionary progress constituting several sets of basic emotions. The *reptile brain*, which is believed to be developed at the early of human age, is the constitution of surviving basic emotions such as *anger*, *fear*, and the *territorial instinct*. The outer layer of reptile brain is known as *mammalian brain* is the area where more complex basic emotions that require memory and feeling reside. Residing as the outer most layer, *primate brain* is the part where reasoning and executive tasks are processed.

2) Affective Space Model (ASM)

From a different perspective, emotions are also postulated to be organized based on a few fundamental dimensions. For an example, a two-dimensional *circumplex model of affect* was proposed in [9] to quantify an emotion based on the level of *valence* and the intensity of *arousal*, as depicted in Fig. 1.

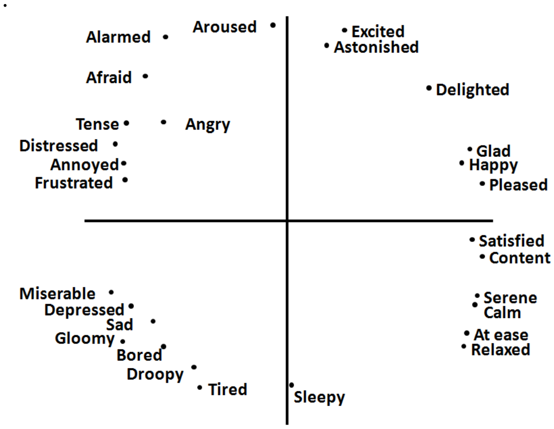

Figure 1. Circumplex Model of Affect from [5]

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Historically, the dimensions of ASM were derived from evaluations of semantic differential scales as implemented in [10]. Semantic differential is one of the techniques used to measure *subjective variables*. In a classical semantic differential, *adjective-word pairs* were grouped into three major dimensions of word meanings, namely evaluative, potency and activity dimensions. Each of the subjective variables was evaluated based on arbitrary scale associated to each of the bipolar adjective words.

Other than semantic differential, various techniques have been proposed to determine valence and arousal values for indicating the coordinates of emotions in the affective space model. For example, in [11], valence and arousal values were measured through self-evaluation of several *appraisal criteria*.

With significant enhancements in neuroimaging techniques, in the recent studies, brain signals are also used as the inputs for measuring valence and arousal values through machine learning methods [12][13].

B. *Electroencephalogram (EEG)*

Electroencephalogram (EEG) is one of the neuroimaging tools used for capturing electrical currents that flow during synaptic excitations of dendrites in cerebral cortex during brain activities. Signals produced by EEG contain high temporal resolutions comparing to other tools. In addition to that, EEG is considered to be a safe and non-invasive apparatus [14].

Brain signals are amplified into delta, theta, alpha and beta based on different frequency ranges. Each of the frequency bandsis very much correspond to specific tasks, as depicted in Table. Theta and alpha frequency bands are generally used for studying emotions [15][16].

TABLE I. EEG BANDS AND DESCRIPTIONS

Bands	Frequency	Description
Delta	1-4 Hz	They are characteristic of deep sleep phases.
Theta	4-8 Hz	Enhanced through sleep mode which usually occur in childhood time.
Alpha	8-13 Hz	Perform naturally in adults thru sleeplessness, under relaxation and mental inactivity conditions.
Beta	13-30 Hz	It distinguishing on the tension stages which in central and frontal locations.

C. *Kernel density estimation (KDE)*

Kernel density estimation (KDE) is a widespread tool used for visualising the delivery of data. Essentially, it is a method that been used broadly used in several implication processes in machine learning, data mining, and others.In addition,kernel estimators smooth out the contribution of each experimental data point over a local area which can be used for feature extraction.

D. *Multi-layer perceptron (MLP)*

Multi-layer perceptron (MLP) is an artificial neural network technique organized in several different layers. The first layer is the input layer containing neurons with the same number of features. The second layer may consist of numerous hidden layers. The number of hidden layers can be determined through optimization process. The third layer is the output layer.

This algorithm is commonly used in supervised learning including classification tasks.

II. METHODOLOGY

A. *Data Collection*

Subjects were 6 children of both genders aged between 4 to 6 years old. Informed consents were obtained from the parents prior to experiment.

During the experiment, each subject was instructed to watch 4 sets of 10 face images extracted from Radboud Faces Database (RafD) [17] corresponding to basic emotions of happy, fear, sad and calm. Each of the sets was displayed and observed for 1 minute.

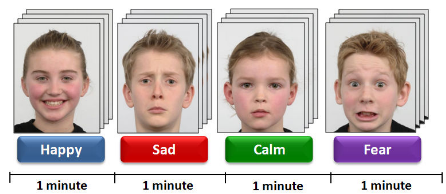

Figure 2. Stimuli presentation flow

The International 10-20 system is adapted for positioning 8 channels of EEG electrodes covering the lobes of the brain including frontal lobe, temporal lobe, parietal lobe and occipital lobe.

B. *Preprocessing*

At the pre-processing phase, signals were filtered to eliminate noises and irrelevant artifacts. For this work, *bandpass filtering* method was employed to extract theta and alpha bands containing emotional artifacts.

C. *Feature Extraction*

To extract features from the filtered signals, Kernel Density Estimation (KDE) was adapted. As a result, 50 features were extracted for each instance.

D. *Training*

In this work, multi-layer perceptron (MLP) was employed to learn and construct classifier of each channel for classifying the corresponding basic emotions based on valence and arousal values set as outputs of the classifier network.

For that purpose, the followings network parameters were configured:

TABLE II. PARAMETERS FOR MLP

Parameters	Values
Number of hidden layer	1
Number of neurons in hidden layer	35
Number of neurons in output layer	2
Mean-square error goal	0.2

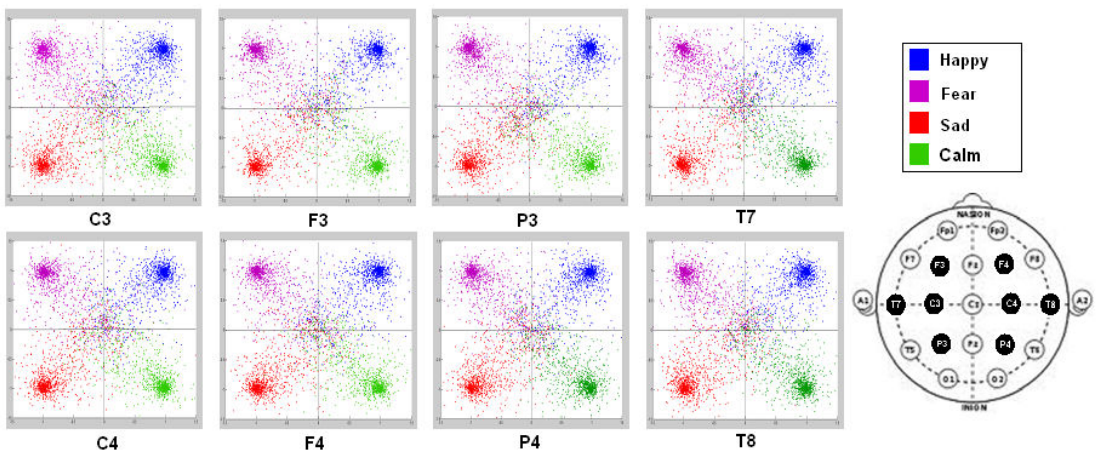

Figure 3. (8 quadrants) Distributions of emotional states at all channels for all subjects; (Scalp topology) EEG electrodes placement.

III. RESULTS

A. Affective state distributions

Fig. 3 shows the distributions of outputs produced by different classifiers representing 8 EEG channels that capture electrical currents generated during emotional elicitations. Outputs for each classifier signify valence and arousal values corresponding to each emotional state.

From the scatter plots, it is observed that all basic emotional states including happy, fear, sad and calm distributed well in the corresponding quadrants as described in ASM. Therefore, the results have also indicated that our approach has constructed good discriminators for classifying these basic emotions per channel.

It has also been noticed that the distributions of all emotions are seen to be consistent at every channel. Hence, this recommends that any parts of the brain are activated during different emotional experiences. This agrees with other findings which stated that emotions are discovered in different areas of the brain [1][2].

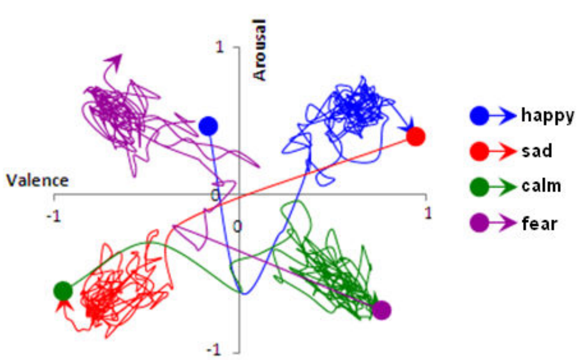

Figure 4. Dynamic of valence and arousal on channel T7 of a subject

B. Affective state dynamics

Besides that, each of the emotional states plotted in all quadrants representing different channels, as displayed in Fig. 3, do not fall in the corresponding affective space. This suggests that emotions do not occur abruptly [18]. Different emotions are also elicited before and after a particular identified emotional state.

The dynamic of emotional states represented by the level of valence and the intensity of arousal is indicated in Fig. 4. The figure shows the change of emotional states captured on channel T7 of one subject participated in the study.

Referring to the figure, initially the subject was at the state of fear. When the first set of stimuli displaying happy faces were presented, the signal moved from fear space to sad space, then calm space, before settled at happy quadrant. When the second stimuli portraying sad faces were presented for another minute, the signal jumped to the sad quadrant. The same scenario happened when the calm faces were present. At the last minute, when the fear faces were displayed, the signal passed through sad region before settled at the fear quadrant.

At other channels, it was also observed that in many cases, signal may fall under different spaces before settling at the expected space.

IV. CONCLUSION AND FUTURE WORKS

Because of any parts of the brain are activated during different emotional elicitations, any EEG channels can be taken into consideration for analyzing emotional experiences. In addition to that, due to the fact that brain signals at specific brain regions are considered to be associated to several cognitive and behavioral activities including learning[19], motor[20], driving behaviors[21], stress[22], and many more, emotion can be used as a reference for the corresponding activities.

Additionally, results have also shown that overlaps occur in the emotional distributions, which indicate that emotion is not static. Emotions change from one state to another before arriving at the target state. Therefore, it will be interesting to investigate in detail about the pre and post conditions of emotional experience by comparing the distribution of valence and arousal measurements of several subjects with different emotional development.

Conjointly, it will also be fascinating to discover the sequence of how channels are activated during different emotional elicitations, so that the underlying process of emotional experiences can be associated with the findings for better understanding of emotional neurophysiology which will be beneficial to biomedical field, especially in dealing with emotion disorders including comorbidity, in which treatment for one disorder may worsen the effect of the other coexisted disorders. For an example, antidepressants taken for curing depression may increase anxiety level.

The link of specific brain waves with emotional states in biomedical research is an on-going process, especially by adapting intelligent system technologies. In a more futuristic treatment, neuro-feedback therapy may also be benefited from the understanding of underlying emotional neural circuits by training the brain to control the central nervous system activities.

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