Wireless EEG Signals Based Neuromarketing System using Fast Fourier Transform (FFT)

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***Abstract*— This work aims to identify the most preferred brand on automotive in Malaysia through wireless EEG signals. A group of four major vehicle brand advertisements such as Toyota, Audi, Proton and Suzuki is considered on this work. An advertisement (video) of above said brands were used to simulate the subjects (9 male and 3 female with age range of 22-24 years) and the brain signal responses for the stimuli were collected using 14 channel wireless Emotiv headset with a sampling frequency of 128 Hz. The acquired signals are preprocessed using 4th order Butterworth band pass filter with a cut off frequency of 0.5 Hz – 60 Hz and smoothed using Surface Laplacian filter. The alpha frequency band (8 Hz – 13 Hz) of EEG signal information has been extracted using the Butterworth 4th order filter. The frequency spectrum of Alpha band is obtained through Fast Fourier Transform (FFT) to extract three statistical features such as power spectral density (PSD), spectral energy (SE) and spectral centroid (SC) from the EEG signals. Extracted features on all the subjects over four different advertisement stimuli are used to develop the feature vector. This feature vector is further given to a two non-linear classifiers namely K Nearest Neighbor (KNN) and Probabilistic Neural Network (PNN) for classifying the subject intention on advertisements. This present experimental results indicate that, the subjects are mostly inspired on Toyota brand vehicles compared to other brands. The maximum mean classification rate of 96.62% is achieved using PSD feature and PNN classifier.**

***Index Terms*—EEG, Neuromarketing, Fast Fourier Transform, K Nearest Neighbor (KNN), Probabilistic Neural Network (PNN)**

I. Introduction

Neuromarketing is a new field of marketing research which is used to investigate the consumer behavior (demands/ needs/ intention) on buying the products using neuroscientific methods. The researcher mainly studied the consumers' sensorimotor, cognitive, and affective response of the product advertisements through different modalities. There are various ways to measure changes in the activity from various parts of the brain, among them are functional magnetic resonance imaging (fMRI), electroencephalography (EEG) and steady state topography (SST), etc [1]. These methods will measure the activities in specific regional spectra of the brain response, and measure changes in one's physiological state [2]. The above mentioned methods are used to investigate the marketing stimuli of different types such as visual (image / posters), audio (radio/music), audio-visual (video). Neuromarketing method is used to study the consumer behavior in a non-invasive way where the consumer cannot convey their intention if explicitly asked. Researchers are interested to investigate on why consumers make the decisions they do, and which part of the brain is activated during their decision to buy the products [1-3].

The conventional method of marketing by means of advertisements in multimedia sources such as radio, television (TV), newspapers, etc may not be successful on selling the products in the market. Since, the advertisement stimuli may not induce a strong intention on all the consumers to buy the item/product. Recent years, most of the famous product manufactures started utilizing the Neuromarketing strategies to evaluate the potential of their product advertisements before launching the product in any part of the world. This Neuromarketing strategy is used to evaluate the potential of multimedia content of their product advertisements and the consumer behavior on their product. This is an emerging field of research, where researchers started working on analyzing the EEG signals for this Neuromarketing field by focusing on different brain regions which are activated during the marketing stimuli, frequency band of information which is useful for detecting the attention state changes of the subject, etc [17].

Electroencephalograms (EEG) are the recordings of the electrical signals of the brain over the entire scalp. These signals are generally voltage variations which results from ionic current flow within the neurons of the brain [4]. EEG is highly preferred by several investigations in the literature to study various clinical and engineering applications such as Neuromarketing due to its non-invasiveness, lesser cost, simplicity, higher temporal resolution, etc. EEG signals are usually analyzed over various frequency bands of information such as, Delta waves, slowest EEG rhythms, generally have the highest amplitude EEG waveforms observed (about 250-325 uV) with all the frequencies below 4 Hz [5-8], Theta waves- typically of higher amplitude and frequencies, 4 Hz - 8 Hz, Alpha waves- this rhythm occurs during relaxed and alert stages, are regular rhythms of 8 Hz - 12 Hz, Beta waves- this band is of smaller voltage and high frequency rhythms (14 to 32 Hz, sometimes as 50 Hz) [5-8]. In attention related studies, researchers have shown their interest on analyzing the theta to alpha band of information's for identifying the consumer's physiological state changes during marketing stimuli [18, 19].

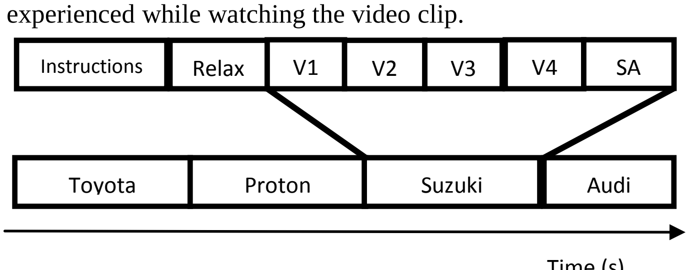
In this work, the researchers are mainly interested to investigate the spectral changes of alpha wave of the subject's during multimedia stimuli (video advertisements) inducement on selecting the most preferred brand of automotive among 4 different brands. EEG signals were taken from 12 subjects over the entire protocol duration. The acquired signals were preprocessed using Butterworth filter and Fast Fourier Transform (FFT) is used to derive the statistical features of the alpha wave from each subject. These extracted features were further given to simple non-liner classifiers to determine the subject's behavior on the product advertisements.

The organization of this paper is given as follows: Section II describes the data acquisition procedure used for data collection and subject's information. Section III describes the methodology of this work, which consists of preprocessing, feature extraction steps, and classification of user states. Section IV presents the experimental results; and finally, conclusions are provided in Section V.

II. Data Acquisition

A. Stimuli and Protocol Design

In this work, we aimed to investigate the customer's most preferred automotive brand in Malaysia. This work considers the four most popular automotive legends in Malaysia namely, Toyota, Suzuki, Proton and Audi. Several numbers of video clips are collected from each brand from various sources such as company websites, You tube, etc. Finally, four video clips of each brand are scrutinized based on the sound quality, display resolution, and its content. Since, the better sound quality and good resolution video might induce better physiological behavior inside the subjects. Each video clip under each brand reflects the different products and the video clips duration is not constant. Thereby, the four different products under each brand are shown to the subjects for evaluating the subject's behavior. The protocol is started with a set of instructions (Figure 1), followed by relaxation scenes and then product advertisements of each brand. All the subjects are seated comfortably on the chair placed in front of the LCD screen and asked them to control their muscular/ wrist/ ocular movements during the experiment. After the completion of viewing each brand video clips, there will be a short session of self-assessment, whereby a few questions will be asked to the subjects such as (i) like or dislike the advertisement (ii) intensity of like or dislike (iii) the emotion experienced while watching the video clip.



Note: V1-V4: Video clips 1; SA: Self-assessment

Fig 1. Flow of experimental protocol

B. Subjects

A sum of 12 subjects that consists of nine male subjects and three female subjects at the age range between 22 and 24 years old considered for this experiment. All the subjects are university students and did not have any history of medical illness such as cognitive/mental/psychological disorders and all of them are non-smokers/drinkers. All the subjects were given a sufficient introduction about this experiment, time duration, purpose of experiment and consent forms are collected from them before entering into the experiment.

C. Data acquisition device

Emotiv EPOC Wireless EEG headset is used for collecting the EEG signals from the subject's using 14 channels. All the electrodes are made up of Ag/Ag-cl material and placed on the subject scalp based on international standard 10-20 electrode placement system (Figure 2). All the electrodes acquired the data from the scalp at the sampling frequency of 128 Hz.

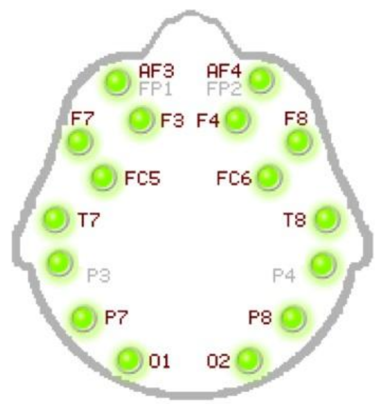


Fig 2. Electrode placement diagram (10-20 International Standard)

III. Methodology

A. Preprocessing

The raw EEG signal was processed to remove the unwanted interferences and the non-signal artifacts [9, 10]. The high frequency components such as power-line interferences also severely introduce noise in the EEG signal [11]. The presence of noise will disrupt and corrupt the signal and as a result, this would make the feature extraction and classification less accurate [9]. Butterworth 4^{th} order bandpass filter is used to remove the low and high frequency noises with a cut off frequency of 0.5 Hz – 60 Hz [12]. Butterworth notch filter with a cut of frequency of 50 Hz is used to remove the power line interference noise [12, 13]. This preprocessed signal is further smoothed using Surface Laplacian filter [12].

B. Framing

The duration of video stimuli are not constant. A minimum duration of video stimuli is 30 sec and maximum of 140 sec. In this work, each stimulus has been framed into a maximum of 5 sec duration without any overlapping. Zero padding is used to make the number of samples on each frame as constant. Since, the intention normally reflects in brain activity of maximum 5 sec duration [20]. Hence, we used to analyze the maximum 5 sec duration of EEG signal on each stimulus in this work. The total number of frames might vary from one trial over other trail and consecutively on brands. An illustration of framing is shown in Figure 3.

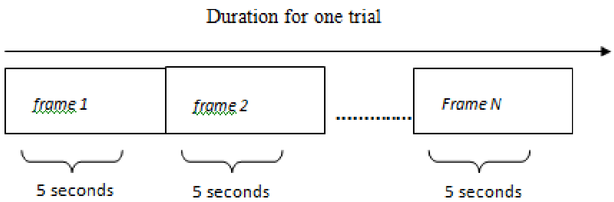


Fig 3: Framing for 5 seconds

C. Feature Extraction

Feature extraction is the main step towards pattern recognition. In the literature, there are many techniques proposed to extract features from physiological signals [12]. In this work, Fast Fourier Transform (FFT) is used to derive the spectral features from alpha wave (8Hz – 13 Hz) of EEG signals. Butterworth 4^{th} order filter is used to extract the alpha wave from each framed signal and three statistical features such as Power Spectrum Density, Spectral Centroid, and Spectral Energy are extracted.

Power Spectral Density (PSD) measures spectral power per unit of frequency and has power/frequency units. Using the PSD, an estimate can be created to understand the signal's frequency content. Expected power in selected frequency is given in Equation 1.

$$PSD = \frac{1}{2\pi}\int_{\omega_1}^{\omega_2} S_x(\omega)d\omega \tag{1}$$

$$S_x(\omega) = \lim_{t\to\infty}\left(\frac{E[F_X(\omega)^2]}{2T}\right) \tag{2}$$

where, F(ω) is the Fourier spectrum output of the input signal, ω_1 and ω_2 are the lower and upper frequency of the power spectrum output.

Spectral Centroid (SC) is used to find the dominant spectral energy from the power spectrum. It is usually used in audio and speech recognition system to detect the dominant frequency from the audio or speech signals. The equation is for computing centroid is given in Equation 3.

$$SC = \frac{\sum_{k=1}^{N} kF(K)}{\sum_{k=1}^{N} F(K)} \tag{3}$$

where, F [k] is the amplitude corresponding to bin k in DFT spectrum.

Besides, the SC and PSD, this work also utilized the spectral energy of the frequency band (alpha wave). The spectral energy distribution in a given EEG signal is obtained through Equation 4.

$$SE = \sum_{k=1}^{N-1} X(k)^2 \tag{4}$$

where, X(K) is FFT spectrum output of the input signal and K is total number of bins in the FFT.

In this work, these features were extracted based on subjective assessment. In other words, the subject who reported as "Like" or "Don't like" after watching the advertisement stimuli are finally used to extract features. Later, these three features were extracted from the alpha wave of the each subject over different number of frames over the trial. The extracted features were concatenated to form up the resultant feature vector for pattern classification.

D. Pattern Classification

Classification is the process of predicting the class of a data subject whose label is unknown using a model derived from a set of data called a training dataset [14]. The features of SE, PSD and SC that were extracted from the original EEG signals are used for the analysis of the classification. The features given are processed into the decision making system in order to identify the subject's decision. There are two classification algorithms used on this work namely, K-nearest neighbors (KNN) and Probability Neural Network (PNN) [15, 16]. KNN is a non-parametric and non-linear method used for classification in several biomedical applications. It assigns a class label to the new entry (testing data) by examining its k-nearest neighbors in the baseline data (training data) [15]. PNN is an implementation of a statistical algorithm called kernel discriminant analysis in which the operations are organized into a multilayered feed forward network with four layers; input layer, pattern layer, summation layer, output layer. The main advantage of the PNN classifier is its faster training process and lesser computational complexity. The above said algorithms require lesser number of external parameters such that the value of K for KNN and σ (spread factor) for PNN compared with other complex machine learning algorithms.

IV. EXPERIMENTAL RESULTS

This work aims to analyze the spectral features of alpha wave of EEG rhythm for human behavior detection on marketing stimuli. The experimental results are narrowed to investigate the performance of different statistical features of alpha wave using two simple non-linear classifiers to understand the consumer's expectations on various automotive brands. The extracted features are validated using K fold validation with a K value of 10. Entire feature set is divided into 10 equal sets of same feature size. Then, K-1 sets are used for training the classifiers and K^{th} set is used for testing. This

TABLE I. DECISION RATE DETECTION ON SUBJECTS USING KNN CLASSIFIER

K value	Power Spectral Density (PSD)				Spectral Centroid (SC)				Spectral Energy (SE)			
	Proton	Audi	Suzuki	Toyota	Proton	Audi	Suzuki	Toyota	Proton	Audi	Suzuki	Toyota
2	86.77	94.16	88.36	**94.71**	58.20	74.57	61.38	87.83	85.71	**95.19**	87.83	93.65
3	78.31	88.66	79.89	92.59	57.14	78.35	62.96	89.42	86.77	94.85	86.77	93.65
4	83.60	90.72	86.77	93.12	60.85	77.66	62.96	89.95	86.77	95.19	87.83	93.65
5	76.19	90.72	75.66	92.06	62.96	81.44	58.73	**91.01**	80.95	93.81	86.77	90.48
6	76.19	90.72	79.89	93.12	61.38	81.10	61.38	90.48	84.66	94.16	88.36	91.53
7	68.78	89.35	67.72	91.01	59.26	79.38	59.26	90.48	82.01	93.13	87.30	89.95
8	71.43	91.75	76.72	91.53	60.32	80.07	62.96	90.48	84.13	93.81	88.36	90.48
9	67.20	90.38	64.55	91.01	57.14	80.41	62.43	90.48	80.95	91.41	86.77	89.42
10	70.37	90.03	70.90	91.01	60.32	81.10	61.90	90.48	82.01	91.75	86.77	90.48

TABLE II. DECISION RATE DETECTION ON SUBJECTS USING PNN CLASSIFIER

p value	Power Spectral Density (PSD)				Spectral Centroid (SC)				Spectral Energy (SE)			
	Proton	Audi	Suzuki	Toyota	Proton	Audi	Suzuki	Toyota	Proton	Audi	Suzuki	Toyota
0.01	71.73	87.91	73.00	95.4	50.63	74.1	59.92	83.21	83.12	90.11	80.59	84.39
0.02	69.2	86.81	68.78	94.51	59.92	72.8	64.56	86.08	83.97	91.21	84.39	94.94
0.03	68.35	85.71	67.51	96.2	59.49	74.18	63.71	**88.19**	81.86	91.48	83.97	94.94
0.04	66.67	85.99	67.51	96.2	59.49	74.18	63.29	88.19	81.01	91.48	83.12	**96.62**
0.05	64.56	85.99	69.62	96.2	59.49	74.18	62.87	88.19	80.59	91.21	81.86	95.78
0.06	66.67	85.99	69.62	95.36	59.92	74.45	63.29	88.19	78.90	90.66	82.70	94.94
0.07	61.6	85.99	68.35	95.36	59.92	75.27	62.45	88.19	77.64	89.84	82.70	94.51
0.08	60.34	85.16	67.51	95.78	59.92	75.55	62.45	88.19	76.79	89.84	82.28	94.51
0.09	59.92	85.16	69.2	95.78	60.34	75.82	62.87	88.19	75.53	89.01	81.43	94.51
0.1	61.18	85.16	68.78	**96.62**	60.34	76.1	63.71	88.19	73.84	88.46	80.59	94.51

TABLE III. OVERALL DECISION RATE DETECTION ON SUBJECTS USING KNN AND PNN CLASSIFIER

Classifier	Features					
	Power Spectral Density (PSD)		Spectral Centroid (SC)		Spectral Energy (SE)	
	% CR	Brand	% CR	Brand	% CR	Brand
KNN	94.71	Toyota	91.01	Toyota	95.19	Audi
PNN	96.62	Toyota	88.19	Toyota	96.62	Toyota

process continued for 10 times and the average accuracy of each feature over 10 folds is reported in Table I and Table II. In this experiment, the value of K in KNN classifiers varied from 2-10 and the spread factor (σ) varied from 0.01-0.1. The maximum mean accuracy of 95.19% is achieved using KNN classifier on Spectral Energy feature compared to other features. The PSD and SC features indicate that, most of the subject "Liked" the Toyota brand in contrast with other automotive brands. Though, the advertisement stimuli of all the brands give more information about several features of vehicles such as, (i) safety (ii) performance rate (iii) fuel consumption (iv) durability (v) depreciation (vi) appearance (vii) multimedia experience (v) cost, etc, but still most of the subjects liked to engage with Toyota models. In Table II, the PNN classifier gives a maximum mean decision rate of 96.62%, 91.01% and 95.19% on PSD, SC and SE features. This PNN classifier also indicate that, the subject prefer Toyota compared to other brands. Table III shows the overall maximum accuracy on each feature over different automotive brands. Analysis of Variance (ANOVA) is also performed on all the features to find the discriminability by setting the significance value of $p<0.01$. This results in the significance rate of 0.006, 0.009, and 0.008 on PSD, SC and SE features, respectively. This experimental result also gives some notable evidences such as Proton and Suzuki shows lesser recognition rate compared to Toyota and Audi. This might be due to the fact that, the subjects are interested to look forward for more comforts, safety, durability, service and rich multimedia experiences on these brand though it's expensive compared to Proton and Suzuki. Also, it's evident that, the proposed methodology on studying the alpha wave features through FFT on three statistical parameters is more suitable to extend this application to other fields of marketing such as food products, mobiles, computers, real estate, politics, banking and other services. This proposed methodology is highly user-dependent and focuses on the physiological characteristics of Malaysian subjects and too university students. Hence, extensive improvements are highly needed to develop a generalized Neuromarketing system. This area of research is not much explored by other researchers and its highly challenging to develop a universal Neuromarketing system. Since, the race, gender, age, ethnic and other social factors play a vital role on improving the decision rate on this research.

V. Conclusion

This present study investigates the consumer's intention on purchasing behavior of four popular vehicle brands in Malaysia for developing intelligent Neuromarketing system. In this preliminary study, we have collected the EEG signals from 12 subjects through 14 wireless EEG channels. Noises present in the EEG signals were effectively removed using Butterworth 4^{th} order filter and FFT is used to extract the three statistical features from alpha wave of EEG rhythm. The extracted features statistically validated using ANOVA and given to two non-linear classifiers (KNN and PNN) for decision making through 10 fold validation method. This experiment indicates that, PNN classifiers and PSD features perform well on subject's data compared to KNN and other statistical features. The maximum mean recognition rate of 96.62% is achieved using PSD features on PNN classifier. This experimental result indicates that, Toyota brand vehicles are highly preferred by the subjects compared to other brands. This is a preliminary study narrowed to investigate the consumer's purchasing behavior on automotive brands in Malaysia. Further analysis on EEG signals over frequency bands, other categories of products, more number of subjects with different age, gender, races is required for developing more generalized Neuromarketing system.

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