EEG Signal Processing for Real Applications

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Abstract The evaluation of human emotions has been a multi-disciplinary area of research interest. Although there are several methods for such evaluation, such as subjective evaluation and behavioral taxonomy, direct evaluation from the human brain is more reliable. Electroencephalograph (EEG) signal analysis is particularly widely used because of its simplicity and convenience. In the present study, human emotional states were investigated using a newly developed EEG device with a single electrode. The developed device is lighter and cheaper than existing devices, although its feasibility is yet to be proven.

Keywords: electroencephalograph (EEG), human emotion, KANSEI, signal processing

1. Introduction

Many services that take personal preference into consideration have been provided in recent times. Hence, the process of the determination of personal preference, which was pioneered in Japan and is locally known as KANSEI, has been actively studied. Whereas sensibility is generally inborn, KANSEI is considered to be a postnatal attribute. There are subjective and objective indexes in the method for determining personal preference. A subjective index is obtained by a questionnaire, whereas an objective index is determined by a bio-signal [1],[2]. In addition, an objective index can be quantified, which enables an objective and engineered approach [3]. Incidentally, there have been many propositions regarding the relationship between an electroencephalograph (EEG) signal and the preference determined by KANSEI in the analysis of a bio-signals [4]-[8]. The propositions are based on the idea that “the state of the brain should change if the state of the person changes because the brain governs the mind, consciousness, recognition, and senses,” as well as other ideas [9],[10]. EEG is one of the bio-signals used as indexes for determining preference in the present study. On the basis of our study, we propose various preference measurement systems for the olfactory sense, acoustic sense, haptic sense, taste sense, and visual sense (generally referred to as the five senses) as well as for a combination of the acoustic and visual senses. In this paper, we introduce the procedure for measuring the EEG and describe the analysis method. We also describe one of the application of the developed preference measurement systems, namely, “KANSEI analyzer”.

2. Analysis of the EEG

An EEG is an electrical signal produced by the activity of the cerebral cortex. It enables flexible and noninvasive measurement of human brain activity with a high temporal resolution. It is well known that the EEG changes in accordance with the mental condition, cerebration, and emotion, and the measurement point is defined by the international 10–20 system. An EEG is generally measured on the basis of this system using multiple electrodes. However, there are some problems associated with the process. For example, more than 30 min is required to position the electrodes. In addition, the subject needs to use a gel as an electrolyte, and this can be stressful. This makes multiple-electrode EEG devices burdensome. We therefore present a simple EEG device that was developed in our collaboration. The EEG is easier to set up and its looseness makes it less stressful to the subject. Moreover, the proposed device measures the EEG activity at Fp1 (left frontal lobe) of the international 10–20 system (Fig.1), using a sampling frequency of 128 Hz. The hair at this measurement point produces very little noise. Furthermore, changes in the EEG mainly occur in the prefrontal area. The simple EEG device is thus considered as being appropriate for EEG measurement to estimate human preference. In addition, the measurement method involves referential recording, wherein the reference electrode is placed on the left ear lobe and the exploring electrode is placed at Fp1. The EEG data are analyzed every second by a fast Fourier transform, and the amplitude spectra can be obtained in the frequency range of 1–64 Hz.
2.1 KANSEI and sensibility

There are two ways of determining human preference, namely, KANSEI and sensibility. These two words are very important in the study of human preference. KANSEI was adopted in the present study. While sensibility is similar to KANSEI, it is fundamentally different. KANSEI is a Japanese word because the study of human preference, as noted earlier, was pioneered in Japan. Sensibility is an innate ability, whereas KANSEI is acquired after birth. The application of KANSEI in the present study was carried out using an EEG device.

![Fig.1 Measurement points of the international 10–20 system](image)

2.2 Simple EEG

This study employed a simple band-type EEG device developed in collaboration with the Dentsu Science JAM co. Ltd. Figure 2 shows the EEG device which our used. The conventional EEG is expensive, large, and cannot be used in a natural environment. The physical features of the device make its use burdensome to the subject. In contrast, the EEG used in the present study is compact, measuring 120 mm (W) \times 135 mm (D) \times 35 mm (H), which makes it less burdensome to the subject. It can also be used in a natural environment. The electrode is fixed to the headband and is positioned at Fp1 of the international 10–20 system, which is shown in Fig. 1. Discrete time data are obtained and the EEG measurement is analyzed every second at a frequency of 24 Hz using 1 Hz intervals. A band filter between 4 and 22 Hz is employed, together with the time series data of each frequency component between 4 and 22 Hz.

The EEG devices in Fig. 3 are of the conventional type, and require a long time to set up. The device in the left photograph requires 45 min to set up, and that in the right picture requires about 30 min. In contrast, our simple EEG device requires only 30 s to set up. It has only one electrode, which makes it easy to set up. The advantages of our device are as follows:
- Reduced number of electrodes.
- Does not require a gel to be worn.
- The subject can easily set up it by himself or herself at anytime and anywhere.

![Fig.2 Our proposed EEG device](image)

2.3 Investigation of preferences

We used a questionnaire to investigate human preference. Although this simplifies the understanding of preference, it cannot be easily used to obtain sequential measurements [11]. However, sequential measurements were required for the present investigation, for which reason we also observed the brain activity.

2.4 Preprocessing for noise, data mining, and pattern recognition

Preprocessing is used to enable the detection of the EEG. The available methods include factor analysis (FA) [12], independent component analysis (ICA), principal component analysis (PCA), and multiple regression. The data obtained from the pre-processing are then mined using a stochastic method such as incremental PCA, fisher linear discriminant analysis (FLDA), simple PCA (SPCA), AMUSE, or SFLDA. The pattern recognition method is subsequently applied to the adopted system. The procedure is illustrated in Fig. 4 and the specific methods that are used are determined by the genetic algorithm (GA).

3. Experiment of human preference detection

3.1 Estimation system for degree of human preference

In this section, we describe the system used to estimate the degree of human preference. We first summarize the system, and then describe its construction. We particularly focus on explaining the methods for EEG measurement and feature extraction, EEG clustering, and multiple regression analysis.

Figure 5 presents an overview of the system for estimating the degree of human preference. The system was used to sequentially estimate the degrees of human preference while watching different TV commercials. First, the simple EEG was used to acquire the EEG data while the subjects watched commercials.

The data were then processed by our system, after which the
results of the degree of human preference were sequentially obtained.

<table>
<thead>
<tr>
<th>Average of the EEG frequency spectrum</th>
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<tbody>
<tr>
<td>Signal analysis</td>
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<tr>
<td>Pre-processing</td>
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<td>Statistical analysis</td>
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<tr>
<td>Pattern recognition</td>
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</tbody>
</table>

Fig. 4 Principle of the proposed method

3.1 Construction of system for estimating the degree of human preference

First, we describe the features of the EEG and the employed questionnaire. We then use cluster analysis to classify the subjects on the basis of the individual characteristics of the EEG [13]. We also explain the cluster analysis. Finally, to estimate the degree of human preference, we conduct a multiple regression analysis of the EEG features and the answers obtained through the questionnaire. The results of the multiple regression analysis are presented.

Questionnaire

The answers in the questionnaire indicated the human emotion or cerebration linguistically. This constitutes a subjective assessment. In this experiment, the subject evaluated the degree of preference for each TV commercial on a scale of zero to ten. The indicated degrees of preference were used for the analysis.

EEG features

The EEG features comprise the EEG data within the amplitude spectra of 4–22 Hz. In this experiment, we assumed that the EEG features reflected the changes in human emotion or cerebration while watching TV commercials. The time average of the spectrum while the subjects watched the TV commercials was applied.

Cluster analysis

Cluster analysis was used to cluster different subjects on the basis of the individual characteristics of the EEG. We particularly employed a hierarchical algorithm and divided each data into successively smaller clusters. Moreover, the distance function was an important factor in the classification. Among the different available distance functions, we adopted the Euclidean function, which is the most commonly used. Furthermore, we determined the effective cluster number by investigating the relationship between the number of data and the number of variables (EEG features) [14].

Multiple regression analysis

We used multiple regression analysis to quantitatively evaluate the degree of human preference. Multiple regression analysis is a multivariate analysis method used to develop a model based on training data. The multiple regression equation, when used as an estimation model, is derived using explanatory and objective variables. In this study, the EEG features were used as the explanatory variables, and the answers in the questionnaire as the objective variable. For this purpose, the answers in the questionnaire were quantified based on the EEG features.

4. Experiment on Watching TV Commercials

In this section, we describe the experiment on watching TV commercials. We measured the EEG while the subjects watched different TV commercials. We also used questionnaires to investigate the degree of each subject’s preference for each TV commercial. The 54 subjects that participated in this experiment comprised 28 males and 26 females. All the subjects watched 10 different TV commercials, each of which ran for 15 s. The simple electroencephalograph was used to measure the EEG while the subjects watched the commercials. After each commercial, a questionnaire was used to investigate the degrees of preference of the subjects. Figure 6 illustrates the experimental procedure. The experimental conditions and data are presented in Table 1 and the questions in the questionnaire are presented in Table 2.

4.1 Simulations

Here, we explain the results of the simulations used to evaluate our system. We performed two types of simulation to discuss the effectiveness of our system. The first was the estimation of the degree of human preference for each of the TV commercials, and the second was the sequential estimation of the degrees of human preference for all the TV commercials.
The results of each simulation are presented. We also verified the effectiveness and generalization of the estimation system, particularly with regard to subject clustering based on the EEG features. To evaluate our system, we define the accuracy rate [%] as follows:

\[ \text{Accuracy} \% = \frac{\text{Correct}}{\text{Total}} \times 100 \quad (1) \]

To calculate Accuracy [%], we used the two commercials with the highest and lowest scores, based on answers obtained by the questionnaire (Q2). We then used the EEG to estimate the degree of human preference. Here, we set \( A \) as the highest value that we estimated by the proposed method and \( B \) as the score obtained by the questionnaire. When there was a high degree of agreement between \( A \) and \( B \), the developed system was considered to be Correct. In addition, Total denotes the total number of data.

Table 3 presents the relationship between the number of subject clusters and the accuracy of the ranking of any two TV commercials by the proposed system. According to the table, the use of two clusters produced the highest accuracy rate. In contrast, we consider that a higher number of clusters would produce higher accuracy because the number of data and variance of the data would be smaller.

### Table 1 Experimental conditions and data

<table>
<thead>
<tr>
<th>Conditions and Data</th>
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<tbody>
<tr>
<td>Number of subjects</td>
<td>54</td>
</tr>
<tr>
<td>Watched objects</td>
<td>10 different TV commercials (Japanese)</td>
</tr>
<tr>
<td>Watching time</td>
<td>15 s for each TV commercial</td>
</tr>
<tr>
<td>Order of presentation</td>
<td>Random</td>
</tr>
<tr>
<td>Experimental period</td>
<td>25–27th August 2010</td>
</tr>
</tbody>
</table>

### Table 2 Questionnaire items

<table>
<thead>
<tr>
<th>S/N</th>
<th>Question</th>
</tr>
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<tbody>
<tr>
<td>Q1</td>
<td>How do you rate your degree of interest in the TV commercial on a scale of 0 to 10?</td>
</tr>
<tr>
<td>Q2</td>
<td>Which scenes are you interested in? (Choose some scenes from the commercials)</td>
</tr>
<tr>
<td>Q3</td>
<td>How many times have you seen the TV commercial previously? (Choose i. 0, ii. 1–3, iii. 4–)</td>
</tr>
<tr>
<td>Q4</td>
<td>How many times have you used the products/services? (Choose i. 0, ii. 1–3, iii. 4–)</td>
</tr>
<tr>
<td>Q5</td>
<td>Rank the TV commercials in descending order of your degree of interest</td>
</tr>
</tbody>
</table>

Considering Table 3, however, in this simulation, we classified the subjects into two clusters because the accuracy rate is not actually proportional to the number of clusters. Furthermore, the effectiveness of the proposed system for estimating the degree of human preference for each TV commercial was confirmed by the determined accuracy rate of 79.6%.

### 4.2 Sequential estimation of degree of human preference for TV commercials

We attempted to estimate the degree of human presence for the TV commercials sequentially. In the previous section, we demonstrated the effectiveness of our estimation system. We then used the system to sequentially estimate the degree of human preference. In using our simple EEG device, the EEG signals transmitted during 1 s were transformed into frequency components. The degree of human preference for the TV commercials was thus estimated every second. However, we applied the moving average to the EEG features because of the necessity to consider the perception time, remainder time, and measurement error. Figure 7 shows an example of the sequential estimation. Each of the graphs indicates upward tendencies around the scenes of interest indicated in the questionnaire. Moreover, there are fluctuations in the estimations for some subjects (see Fig. 8). Furthermore, according to Fig. 8, there were several scenes that interested the subjects. However, there were still significant fluctuations in the degrees of preference estimated by the system. The observed fluctuations in the results indicate that the degree of human preference cannot be fully understood by a questionnaire. However, interpersonal differences can be evaluated using a questionnaire.
Figure 7 (a)-(d) Results obtained by the proposed system

(a) Subject 1/CM7

(b) Subject 13/CM1

(c) Subject 34/CM9

(d) Subject 43/CM8

Fig. 7 (a)-(d) Results obtained by the proposed system

From these results, you can find that in the case of using the questionnaire, we cannot detect the interest degree in an online manner. In the case of using the proposed method on the contrary, you can obtain the interest in an online manner. From these results, it was confirmed that the proposed method works well.

4.3 Sequential estimation of degree of human preference by the conventional method without questionnaire

For the purpose of comparison, we show the conventional method that used near infrared spectroscopy (NIRS). In this method, blood oxygen strength is detected on the brain while subjects watched the TV commercials. By using this device, there are long delays and we cannot see the correct reaction points on the TV commercials. Then we could not evaluate the TV commercials sequentially. On the contrary, we apply the proposed method to this evaluation, we could get good results by online (see Fig. 9). X and Y axis indicate time sequence and human interest, respectively. As you can see Fig. 9, it was confirmed that the proposed method works very well.

4.4 Online human interest measurement system using EEG

We apply the proposed method to a real product. We developed online human interest measurement systems using the iPad (see Fig. 9). Moreover, by using this system, we can get the TV commercials evaluation (Fig. 10). We named this system “KANSEI analyzer”. This system can measure human interest in an online manner, we can get the good result for TV commercials evaluation.

5. Conclusions

In this paper, we developed new evaluation systems for TV commercials by using EEG. We focus on human KANSEI, and detect human interest using the EEG. The developed systems enable the determination of the importance of different frequencies and their combinations for obtaining the interests while they watching the TV commercials. Moreover, the applications used for the evaluation were structured for use anywhere. In the simulation, the EEG data were transferred to the iPad by Bluetooth, and EEG feature detection, cluster analysis, and Multiple regression analysis was used.
Fig. 8 A sample of the real results obtained by the proposed method. (red rectangular indicate the chosen situation as human interest)

Fig. 9 Online human interest measurement system using iPAD(KANSEI Analyzer ©Dentsu science JAM)

References


**Yasue Mitsukura** received the D.E. degree from the University of Tokushima in 2001. She worked at the University of Tokushima and Okayama University as an Assistant Professor and a Lecturer, respectively. From 2005 to 2010, she was an Associate Professor at Tokyo University of Agriculture and Technology. Since 2011, she has been an Associate Professor at Keio University. Her interests are signal processing, EEG analysis, and image processing. She is a member of SICE, IEEJ, RISP, Auditory, AIJ, IPS, and IEEE.

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