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EEG Based BCI Using Visual Imagery Task for Robot Control

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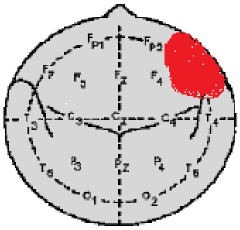
Graphical Abstract



Abstract

The aim of this study is to detect the brain activation on scalp by Electroencephalogram (EEG) task-based for brain computer interface (BCI) using wirelessly control robot. EEG was measured in 8 normal subjects for control and task conditions. The objective is to determine one scalp location which will give signals that can be used to control the wireless robot using BCI and EEG, using non invasive and without subject training. In control condition subjects were ask to relax but in task condition, subjects were asked to imagine a star rotating clockwise at position 45 degrees direction pointed by the wireless robot where at this angle the target is located. At position 0 and 90 degree angle subjects were asked to relax since there is no target on that direction. Using EEG spectral power analysis and normalization, the optimum location for this task has been detected at position F_8 which is in frontal cortex area and the rhythm happened at alpha frequency band. At this position, the signals from the brain should be able to drive the robot to the required direction by giving correct and accurate signals to robot moving towards target.

Keywords: Electroencephalography (EEG); Brain-computer interface (BCI); visual imagery; right frontal cortex

Abstrak

Matlamat kajian ini adalah untuk mengesan keaktifan otak melalui kulit kepala dengan *Electroencephalogram* (*EEG*) untuk pengantaramuka computer otak (*BCI*) menggunakan robot tanpa wayar. EEG telah diukur dan direkod pada 8 subjek yang normal untuk keadaan terkawal dan tugasan. Objektifnya adalah untuk menentukan satu lokasi di kulit kepala yang akan memberikan isyarat yang boleh digunakan untuk mengawal robot tanpa wayar menggunakan *BCI* dan *EEG*, menggunakan prosedur bukan invasive dan tanpa perlu melatih subjek. Dalam keadaan terkawal, subjek diminta untuk bertenang, namun dalam keadaan tugasan, subjek diminta untuk mengimaginasikan sebutir bintang berputar mengikut arah jam pada kedudukan 45 darjah seperti ditunjukkan oleh robot tanpa wayar dimana pada sudut ini terletaknya sasaran. Pada kedudukan 0 dan 90 darjah subjek diminta untuk bertenang kerana tiada sasaran berada pada sudut ini. Menggunakan analisa power spectrum ke atas *EEG* dan penormalan, kedudukan optimum untuk tugasan ini telah dapat dikesan di kedudukan F_8 iaitu dalam kawasan korteks hadapan dan ritmanya berlaku di jalur frekuensi alfa. Di kedudukan ini, isyarat-isyarat dari otak sepatutnya boleh mengawal robot dengan memberi arah yang betul setelah diberi isyarat-isyarat yang tepat untuk robot bergerak ke sasaran.

Kata kunci: Electroencephalography (EEG); Brain-computer interface (BCI); imaginasi visual;korteks depan kanan

■1.0 INTRODUCTION

Brain electrical activities can be measured through invasive (Electrocorticogram–ECoG) and non-invasive (Electroencephalogram–EEG) method. The invasive method is where the electrodes are implanted underneath the scalp that may involve clinical risks and substantial technical difficulties.[1] On the other hand, EEG is known as a procedure to measure electrical signals from scalp produced by monitoring neurons activities in brain, captured non-invasively which is rather safe, doable and low risk procedure where the electrodes are place on the scalp without the need of surgery.[2] Brain computer interface (BCI) is a device that translates EEG signals into a command that can be understood by and operates any technical devices.[3] BCI can be used in application such as moving robot,[4] control of cursor movement[5] or spelling software,[6] control of wheelchair[7] or control of any other devices.

The common problem nowadays for people with motor disabilities or motor dysfunctions is the requirement for the alternative communication in order to communicate rather than just being locked inside their body. EEG-based BCI is primarily used to enable people with severe motor disabilities,[8] people who are totally paralyzed (e.g., amyotrophic lateral sclerosis (ALS) or brainstem stroke) or people who lost control over every motor output in which the people transmit information by brain activity without conventional peripheral nerves and muscles.[9] Common routine for EEG and BCI system requires training every time the electrode cap is placed on subjects[10] and often it needs more than one electrode to transmit the signals from scalp.[11] Therefore it requires longer time to implement and process the data to get the best accuracy on controlling the device during real application.

In order to reduce the training session, a task should be device. Motor imagery task is a tool to differentiate the desired and undesired EEG signals. A specific task allowed the brain to give different signals during the visual imagery task and relax condition. Since more than 20 years back motor imagery has been known to provide very similar way as observable with real executive movements by modifying the neuronal activity in the primary sensorimotor areas.[12] There are many motor imagery tasks have been done such as motor imagery of left and right hand movement,[13] a multiplication task, a geometric rotation task, a letter composition task, and a visual counting task.[14] Nowadays, various motor imagery tasks have been done in the study of translating EEG signals into a command to control output devices. This will enhance the build of other prototypes systems for EEG-based BCI and become as a foundation and contribution in the areas of cardiology, muscle physiology and neuroscience by the increasing knowledge along with comprehension about motor dysfunctions.[15]

In this study the objective was to use non-invasive method, having only one scalp location to send signal to robot without subject training. The advantages are that disable people need only one electrode attach on the scalp without the need of surgery and training session, while controlling robot wirelessly. In order to achieve this, identification of the best location on the scalp that can be used to control the robot must be obtained.

2.0 METHODOLOGY

2.1 Data Collection

2.1.1 Experimental Setup

Using EEG data monitoring equipment from Nihon Kohden, an EEG cap with 19 channels/electrodes were placed on the scalp of a subject based on 10-20 electrode placement systems. Robot was connected wirelessly to the BCI (Figure 1). A program using LabVIEW was created to control robot movement and send triggering signal to EEG machine from BCI. The signal was sent wirelessly to the robot via Xbee connection while connection to the EEG machine was via NI-USB6008.

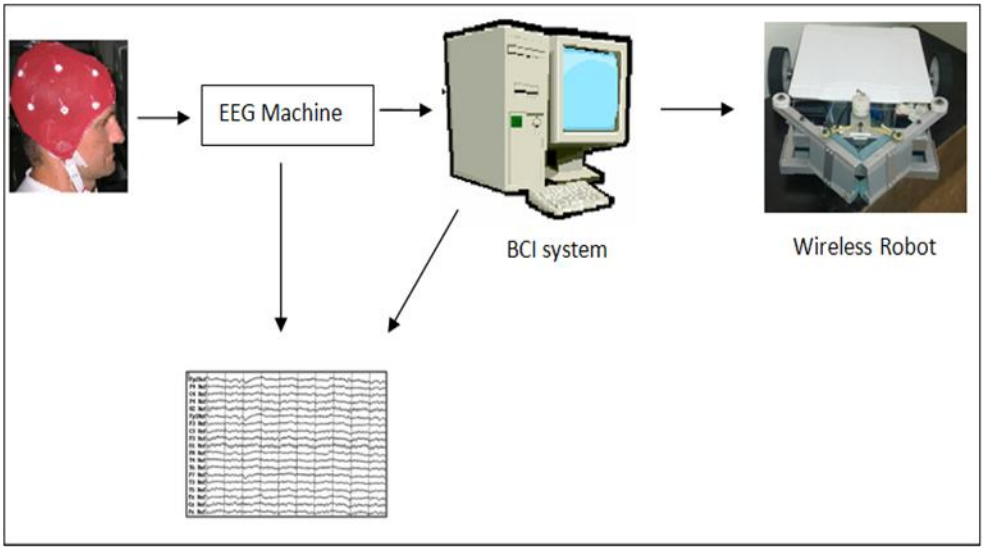


Figure 1 Experimental setup

2.1.2 Human Subject

8 healthy human subjects aged 23-30 years old participated in this study. They have never been tested on any research (never had training session) and does not have any health problem. They gave informed consent to participate in these experiments.

2.1.3 Condition

Subjects sat on a chair facing a robot which was located about two feet away from their feet. Two conditions were applied, i.e. Control condition and Task conditions. In Control conditions, subjects were asked to relax (resting) and were instructed to fix their eyes at the robot in front of them. In Task condition, subjects were asked to imagine a star rotating clockwise when the robot is facing the target. In this Task condition, robot scans through three angles, i.e. 0, 45 and 90 ° to check for target location. Subjects were asked to relax when angle 0 and 90 ° because there was no target in the direction of those particular angle location (non-target). At angle of 45 °, subjects were ask to imagine the star rotating clockwise (target) for about 10 seconds starting right after the robot turned the direction from 0 to 45 degrees, until the robot change again its angle to 90 °.

2.1.4 Data Acquisition

EEG signals were obtained according to 10-20 electrode placement system with reference electrodes attached to left ear (for electrodes on left side of the scalp) and right ear (for electrode on right side of the scalp). EEG signals were recorded with pass bands of 0.5 - 120 Hz and stored in a computer with a sampling frequency of 1 kHz. They were recorded for 10

seconds each condition. A single trial that comprises of Control and Task condition (all angles) lasted for 40 seconds and was repeated four times. As this study focuses on robot movement signal analysis, the basic step of BCI system was followed.
First, EEG signal was recorded from the scalp through 19 electrode channels and digitized using acquisition system from the EEG machine. Then the digitized signals were manipulated to feature extraction procedures, such as power spectral analysis. After such feature extraction, the system has enough information to brain map the activated location on scalp

2.1.5 Frequency Classification

EEG frequency classification follows standard set by Terminology Committee of International EEG Waveform society as shown in Table 1.

Table 1 Frequency ranges in EEG signal

Frequency band	**Range**
Delta	$0 \leq \delta < 4$
Theta	$4 \leq \theta < 8$
Alpha	$8 \leq \alpha < 13$
Beta	$13 \leq \beta < 31$
Gamma	$31 \leq \gamma < 51$
High gamma	$51 \leq \text{high } \gamma < 120$

2.2 Data Analysis

EEG signals were converted into frequency domain using FFT[16] which represent the time domain in a power spectrum value divided into six frequency bands as in Table 1.

The EEG data were divided into 10 intervals with each interval consists of 1024 data points (1 second data). For Control condition, the power spectrum data were averaged over 10 intervals. The power spectrums at every frequency in Task condition were compared to get the maximum difference in power (DP).

$$\text{Difference power (DP)} = \text{power in task} - \text{power in baseline} \quad (1)$$

where baseline is the average value of power of Control condition.

The DP values were averaged over 10 intervals and over four trials in order to get the ideal value of power spectrum for each frequency band. Then the values were calculated to find the power changes at each angle. For condition-related power change was expressed as:

$$(\text{power}_{\text{condition}} - \text{power}_{\text{control}}) / \text{power}_{\text{control}} \quad (2)$$

2.3 Statistical Analysis

Analysis of variance (ANOVA) with repeated measures (within subject changes) was used for multiple comparisons. The ANOVA factor used three levels, i.e. 0 (non-target), 45 (target) and 90 degrees (non-target). Other factors were the frequency band with six levels (delta, theta, alpha, beta, gamma, high gamma) and channels with 19 levels. If a significant effect was identified, post-hoc testing was applied for multiple comparisons. The significance level was set to $P < 0.05$.

■3.0 RESULTS ANALYSIS

No statistical difference between any of the signal was observed using difference in power (DP). However, when the power changes at each angles were calculated, obvious changes were observed (Figure 2). Figure 2 shows topographic map of condition related power changes for delta, theta, alpha, beta, gamma, and high gamma.

Spectral power changes between non-target and target conditions were observed at frontal region in delta, alpha and beta frequency bands (Figure 2A). In contrast, not much power changes were seen between 0 and 90 degrees where both were non-target. Statistical analysis was done to find whether the changes were significant or not. Using minitab software, ANOVA has been done to the normalized data. Normalized data is condition-related power changes data. The interaction between Task angles, frequency band and electrodes position on scalp were observed.

T-test values are shown in Table 2 for non-target and target conditions. P-value and df value for each electrode position from ANOVA were also included in the table. From the table, the most significant difference was found at F_8 location in alpha frequency band ($P < 0.001$). At F_8 location, the repeated-measure ANOVA revealed significant interaction between condition × frequency band ($F_{10,70}=5.31$, $P=0.001$). Beyond this results, t-test were done to determine which channel means differ from each other where the results have shown significantly that location F8 has given P value for less than 0.01 which means there is 99% significant difference between the data groups which is the highest among the results.

In contrast, no significant difference was found between 0 degree and 90 degree conditions (both are non-target) in the EEG power spectrum in any frequency range (condition × frequency band, with $P > 0.05$). At this point ANOVA concluded that null hypothesis for all 19 channels are equal and dependent have not been rejected since the value of $P > 0.05$. This concludes none channel mean is significantly different from the others.

■4.0 DISCUSSION

This study observes the maximum difference in power between resting and active task in which the experiment use visual imagery of moving object (rotating a star clockwise. However no significant difference was found for the maximum difference in power between conditions. On the other hand, the condition-related power changes, showed significant difference between target and non-target. The most significant difference was found at F_8 location in alpha frequency band.

Frontal lobe which includes F_8 location is structure which inhibits responses to the environment, planning future action and control the movement.[17] Imagery related condition also involves right- frontal cortex. Compared with other experimental conditions, mental imagery was associated with stronger activity in frontal and parietal regions mainly on the right. A study from[18] shows fMRI results from visual imagery of brisk walking activated at right frontal cortex. Their results support the findings of this study.

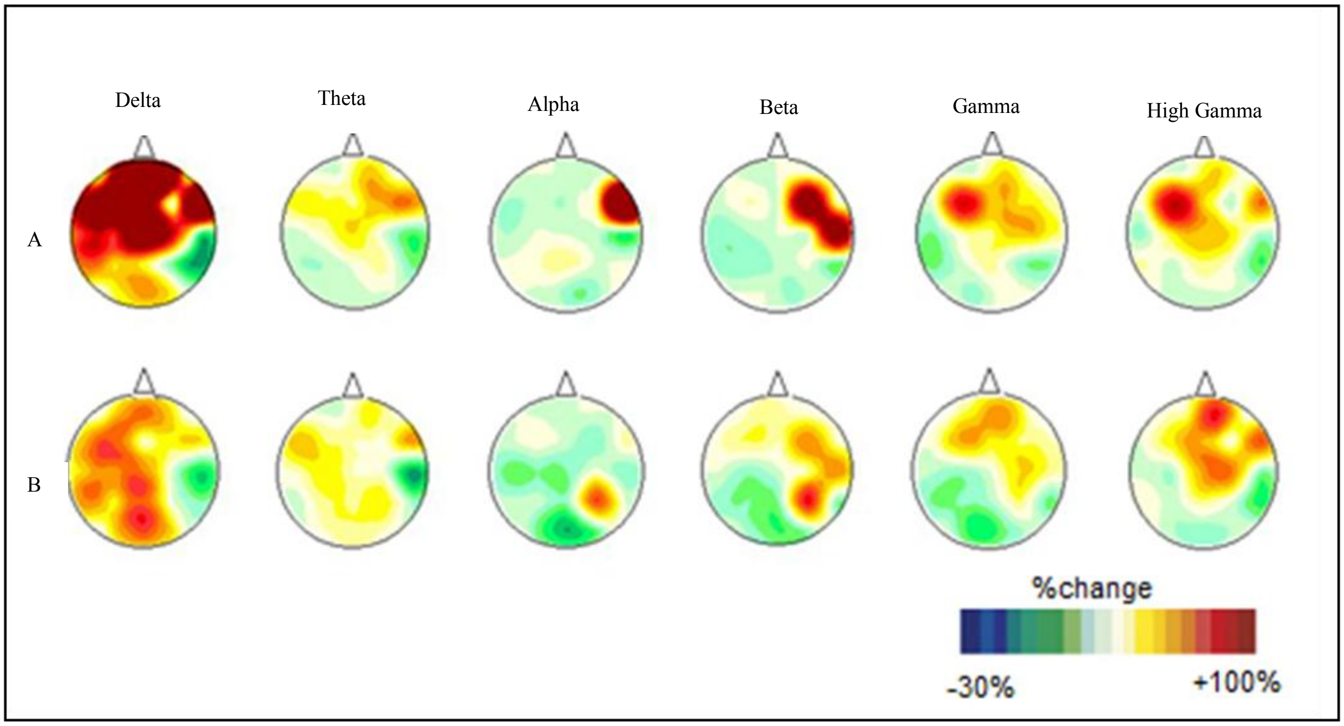


Figure 2 Topographic map for condition related power changes. A: changes between angle 0 and 45 degrees (non-target and target conditions). B: changes between 0 and 90 degrees angle (both are non-target)

Table 2 Values of t-test for all 19 channels at each frequency band and ANOVA p-value for 0-45 ° angle

ttest	delta	theta	alpha	beta	gamma	hgamma	ANOVA	
	0-45	0-45	0-45	0-45	0-45	0-45	df	p-value
Fp1	0.049*	0.661	0.042*	0.078	0.256	0.368	5	0.014
F7	0.110	0.295	0.098	0.206	0.478	0.970	5	0.038
T3	0.246	0.469	0.383	0.189	0.421	0.482	5	0.193
T5	0.067	0.010*	0.554	0.233	0.418	0.351	5	0.013
O1	0.467	0.024*	0.363	0.645	0.020*	0.056	5	0.520
F3	0.172	0.107	0.029*	0.180	0.938	0.659	5	0.057
C3	0.150	0.297	0.174	0.170	0.474	0.954	5	0.058
P3	0.417	0.234	0.738	0.305	0.854	0.771	5	0.596
Fz	0.119	0.199	0.004**	0.157	0.912	0.993	5	0.020
Cz	0.094	0.095	0.008**	0.190	0.788	0.694	5	0.009
Pz	0.579	0.469	0.867	0.244	0.773	0.554	5	0.849
F4	0.120	0.109	0.023*	0.221	0.892	0.996	5	0.021
C4	0.031*	0.108	0.104	0.039*	0.452	0.036*	5	0.000
P4	0.422	0.260	0.938	0.202	0.616	0.706	5	0.572
Fp2	0.157	0.726	0.049*	0.148	0.480	0.428	5	0.125
F8	0.032*	0.339	0.001***	0.126	0.141	0.696	5	0.001
T4	0.706	0.750	0.846	0.657	0.548	0.605	5	0.971
T6	0.938	0.955	0.554	0.419	0.953	0.896	5	0.970
O2	0.187	0.351	0.613	0.012*	0.493	0.308	5	0.136

Indicator:

* : $p < 0.05$

** : $p < 0.01$

*** : $p < 0.001$

In previous brain imaging studies, it was found that fronto-parietal networks were activated during specific visual imagery tasks which also underlie the spatial analysis of mentally imagined representations.[19-20] The activation of frontal regions is common to all mental imagery tasks .[21] In addition, a recent study from[22] identified that frontal cortex brain region subserving the visual imagery of complex scenes resulted at theta and beta oscillations. They studied visual imagery of complex scenes to investigate the spectro-temporal properties of its nodes. Meanwhile this study investigates the power-related spatial distribution in the brain during the motor imagery task found right-frontal region activation at alpha frequency band. Visual imagery of star rotating may contributes to the increase power in alpha frequency band at the right-frontal region as bold in red color in Figure 3.

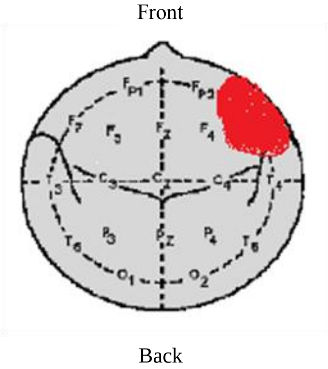


Figure 3 The location of right-frontal region

■5.0 CONCLUSION

From the finding, it is concluded that alpha frequency band at right-frontal region may be used to control robot to the direction of the target location. It will be simple to control the wireless robot for a subject since no surgical needed, only one electrode attach to the scalp and no training session needed for the subject to do the task and control the wireless robot. Future work for this study can be done by doing on-line and real time analysis to a patient. The main concern in future work can be the accuracy, precision, and a shorter time taken to complete the task.

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