APSIPA ASC 2011 Xi'an

Hybrid EEG-HEG based Neurofeedback Device

Supassorn Rodrak*, Supatcha Namtong†, and Yodchanan Wongsawat**
Department of Biomedical Engineering, Faculty of Engineering, Mahidol University, Nakhon Pathom, Thailand
E-mail: *supassorn_7@yahoo.com, †supatchanamtong@gmail.com, **egyws@mahidol.ac.th
Tel: +662-889-2138 Ext. 6351

***Abstract*— Attention Deficit/Hyperactivity Disorder (ADHD) is one type of brain disorder suffered by 6.5% of children in Thailand. The well-known method for treating is by using drug. However, using the drug might lead to some side effects, for example, vomit, dizziness and headache. To avoid these kinds of side effects, neurofeedback is an alternative way for treating ADHD. The signals often employed in neurofeedback are EEG (electroencephalogram) and HEG (hemoencephagram). EEG is the brain wave that changes its frequency in conjunction with brain activities. HEG is the measurement of brain blood flow that changes along with blood oxygenation. There are different advantages/drawbacks of both signals. In order to eliminate the disadvantages of both signals, this paper proposes the hybrid EEG-HEG neurofeedback device which employs both signals to achieve the highest neurofeedback performance. Experimental results show that the proposed hybrid system can efficiently eliminate the artifact problems occurred from using only the EEG. Moreover, the system can improve the low changing rate occurred from using only the HEG.**

I. INTRODUCTION

Attention Deficit/Hyperactivity Disorder (ADHD) is a neurobehavioral disorder which leads to the difficulty on focusing, paying attention and controlling normal behavior. In Thailand, the prevalence of ADHD is estimated to be 6.5% [1]. It is currently a public health concern because of the diagnosis of a large and growing number of children. Medicine has been widely used for the treatment of ADHD symptoms, but the children may have a chance to suffer from the side effects of drug, such as vomit, rash, urticaria, cardiac arrthymia and insomnia [10].

Neurofeedback device is known as one of the efficient alternative way for treating ADHD [2-5] since it can solve those mentioned concerns. This simple but efficient device non-invasively employs the potential change in the brain called electroencephalogram (EEG) and the brain blood oxygenation change called hemoencephalogram (HEG). For EEG neurofeedback, the patient needs to maintain the beta activities (13-30 Hz) while reduce the alpha activities (7-13 Hz) [1, 11]. For HEG neurofeedback, the HEG needs to be continuously increased to some setting thresholds of the brain blood oxygenation levels [6-9]. Even though the EEG and HEG directly illustrate the functional of the brain, EEG is sensitive to artifacts such as eye-blinking, motions, 50-Hz noise etc., while HEG slowly responses to the brain blood oxygenation. Hence, to eliminate the disadvantages from both signals, the proposed hybrid EEG-HEG based neurofeedback device aims to make ADHD patients to maintain efficient EEG frequencies simultaneously with HEG levels regarding the attention behaviors. The proposed system consists of three modes. The patients can select one of the three modes from graphic user interface (GUI), i.e. EEG mode for processing only the EEG signal, HEG mode for processing only the HEG signal, and hybrid mode for simultaneously processing both EEG and HEG signals. In order to visualize the feedback, car racing game is employed, i.e. if the patient can concentrate, the car will move forward otherwise it would stay still.

II. METHODOLOGY

A. System Overview

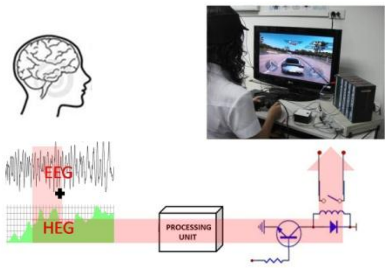


Fig. 1 Process Summary of the Overall System

According to Fig. 1, the system starts when the processing unit acquires the EEG and HEG from the patients. The decision will be sent to the control unit to command the car racing game. The car will move forward only if patients have the attention. The attention levels can be quantitatively evaluated via the 1) EEG, 2) HEG, and 3) both EEG and HEG.

B. Proposed System

1. Finding Optimal Threshold via Linear Classification

Since the attention ratios need to be designed specifically for each person, therefore, the proposed system provides three calibration modes to calculate the optimal thresholds via 1) EEG, 2) HEG, and 3) both EEG and HEG. By letting the patient performs both the attention and non-attention tasks, linear classification is employed to calculate the optimal threshold with respect to the selected input signals, i.e. we first need to find *w* from (1),

$$w = (x^T x)^{-1} x^T y \;, \qquad (1)$$

where *x* is the two column matrix consists of two types of training data (Attention and Non-attention), and *y* is the column vector consists of the template regarding the known positions of the two-class data in *x*.

From (1), *w* is the two dimensional column vector, each element is denoted by *w*(1) and *w*(2). Hence, the *threshold* can be calculated from the following equation:

$$threshold = -\frac{w(2)}{w(1)} . \qquad (2)$$

2. *Signal Acquisition and Processing of the EEG and HEG Neurofeedback*

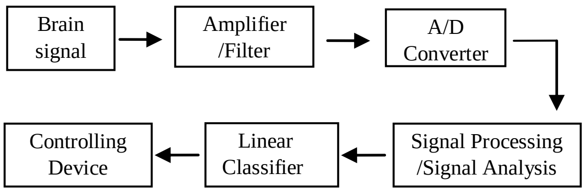


Fig. 2 Neurofeedback system overview

According to Fig.2, firstly, analog signals from the patients are amplified by the amplifier circuits (Biopac™ MP 100 amplifier for EEG and home-made amplifier for HEG with Toomim nIR sensor). Secondly, it is converted to the digital signals by A/D converter (EEG sampling rate is 200 Hz, HEG sampling rate is 500 Hz). Thirdly, digital signals are processed real-time in the computer via the selected filtering methods. The resulting features are classified via linear classifier and give the decision to command the selected visual feedback devices.

In this paper, car racing is the game that we use to give the visual feedback of the brain functional to the patient. Decision making from the classifier would directly use to control the joystick via the relay circuit. If the patient focuses on playing game, speed of the car will be increased. Similarly, if patient does not pay attention to the game, speed of the car will be decreased.

2.1) EEG algorithm

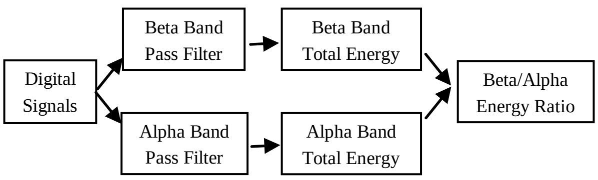


Fig. 3 Process of proposed EEG neurofeedback system

According to Fig. 3, to further emphasize on the aspect of digital signal processing, digital signals are filtered into two frequency bands, i.e. alpha band (7 – 13 Hz) and beta band (13 – 30 Hz) by Butterworth IIR Filter 9th order. To evaluate the contribution of each band at the same time, we use the index ratio calculated as follows:

$$Ratio = \frac{E_{beta}}{E_{alpha}} \;, \qquad (3)$$

where *E* denotes the energy with respect to the subscript EEG frequency bands. *E* can be calculated as

$$E = \sum x^2(n) \,, \qquad (4)$$

where *x*(*n*) is the digital EEG signal at the *n*-th sample.

2.2) HEG algorithm

Hemoencephalography (HEG) measures the changes of blood oxygenation related to the brain activities. Near infrared (nIR) HEG employs principles of the light absorption of hemoglobin, i.e. oxyhemoglobin (HbO_2) will absorb the red light (600-750 nm) more than the infrared light (850-1000 nm) and deoxyhemoglobin (HbR) will absorb the infrared light more than the red light. If the brain performs high activities, the quantity of oxygen in blood will be increased. This means that it has oxyhemoglobin more than deoxyhemoglobin. The nIR HEG sensor measures intensities of the red light compared with the infrared light reflected back to the headband. We can calculate the HEG by using the following equation:

$$HEG = \frac{red}{Infra - red} \qquad (5)$$

where *red* is the intensity level of the red light reflected back to the detector and *Infra* is the intensity level of the infrared light reflected back to the detector.

2.3) Decision making process

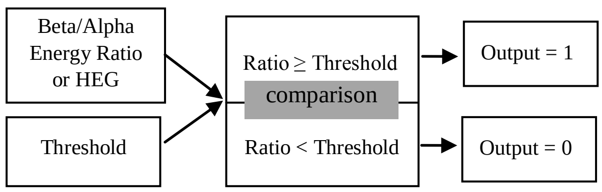


Fig. 4 Decision making process

According to Fig. 4, if the EEG ratio or HEG level is more than the setting threshold, digital output will be 1 (on). This case implies that patient is in the attention state, and speed of the car in the game will be increased. Similarly, if the EEG ratio or HEG level is less than the threshold, digital output will be 0 (off). This case implies that the user is in a non-attention state, consequently speed of the car in game will be decreased.

3) Hybrid Condition: EEG - HEG Neurofeedback

EEG and HEG sensors are different in properties. Advantage point of EEG sensor is that EEG can be acquired all over the brain position on the scalp. Moreover, EEG has the very fast response with brain functional. For the good point of HEG sensor is that it is more stable to artifact compared with EEG, but it has the slow response with brain functional. Moreover, HEG can be efficiently used only in the frontal lobe of the brain (the area with no hair). Therefore, using both EEG and HEG sensors simultaneously will support the system ability and decrease the weak points of the existing neurofeedback systems.

The EEG and HEG outputs can be computed by the EEG and HEG neurofeedback methods in sections 2.1 and 2.2, respectively. Simply, the decision in the hybrid system will be on only if both EEG **and** HEG outputs are on ("on" means the car moves forward).

C. Experiment to Find the Appropriate HEG Calibration Activities

Traditional HEG systems normally emphasize on only the increasing of HEG levels. Therefore, in every experiment, the lighting conditions need to be controlled. To overcome this disadvantage, we propose the calibration method via linear classification. To efficiently find the training activities for attention and non-attention that efficiently reflect the HEG, some experiments need to be conducted. That is we design the experiments for finding the appropriate activities that can separate attention and non-attention states (Two non-attention tasks and two attention tasks are conducted).

Task 1 is a non-attention task; the subjects close both eyes and relax.

Task 2 is another non-attention task; the subjects are in the relaxing state with both eyes opened.

Task 3 is an attention task; the subjects play racing car game (focusing on the game).

Task 4 is another attention task; the subjects calculate the mathematical problems.

For each task, we will record HEG for 50 seconds. Ten subjects are participated in the experiments.

III. RESULTS AND DISCUSSIONS

A. The HEG Testing Results

After performing all four tasks in section II C, each subject has different values of HEG (due to the lighting conditions) but the values change in the same way for each activity. According to Fig.5, eye-closing (Task1) is the better activity to enhance the non-attention level than relaxing while eye opened (Task2). For attention task, Task 3 and Task 4 are comparable except for subject 4. Hence for convenience with the real-time feedback design, Taks3 is selected as the attention activity. This also means that the values of HEG vary in the same way with the frequencies of EEG (high frequency of EEG for high brain activity).

B. The Specificity and Sensitivity of EEG and HEG Neurofeedback

By using Task 1 as the non-attention task and using task 3 for the attention task, we calculate the specificity (the percentage of attention that correctly identified as not having the condition) and sensitivity (the percentage of non attention that correctly identified as having condition) of both EEG and HEG system.

The EEG neurofeedback specificity is 70 % which is less than the HEG neurofeedback specificity of 94%. The EEG neurofeedback sensitivity is 90% which is greater than the HEG neurofeedback sensitivity of 29%. This means that EEG is changed rapidly when we change activity but the HEG is changed slowly when we change activity. However, the HEG is more robust to the artifacts than the EEG.

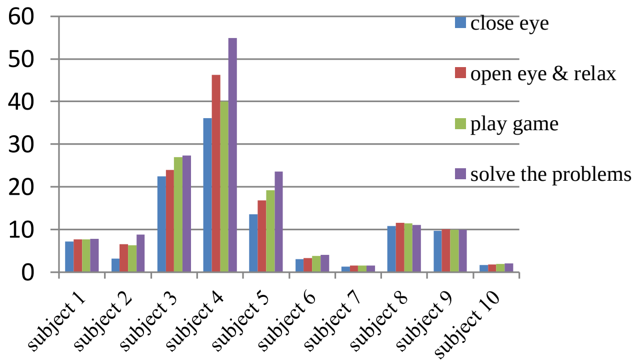


Fig. 5 The bar graph show the different HEG level (*y*-axis) for each activity and each subject

C. The Response of Signals to the Brain Activities

According to Figs. 6 and 7, we conduct the simple experiment with one subject to illustrate the response time of the signal changing rate from attention state to non-attention state (other subjects also show the similar respond time). For EEG, it takes about a second, however for HEG it takes about 15 seconds**.**

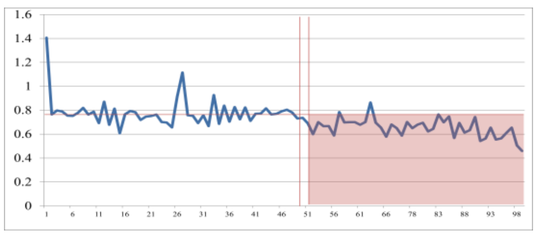


Fig. 6 The graph shows EEG changing rate when the patient changes the activities.

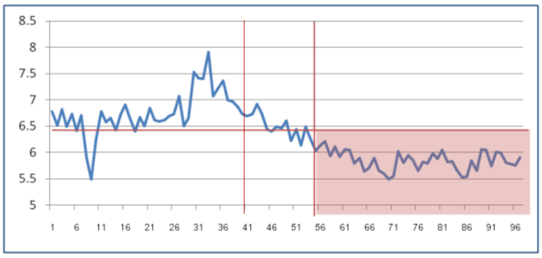


Fig. 7 The graph shows HEG changing rate when the patient changes the activities.

D. User-Friendly Program for Calibration

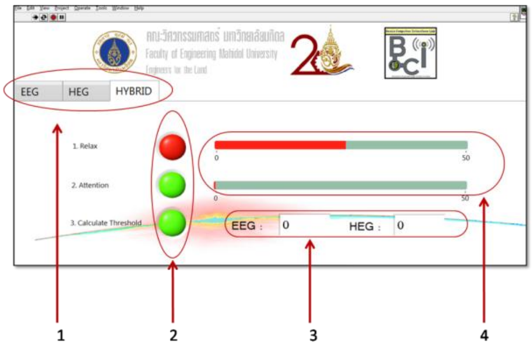


Fig. 8 GUI of the program for calculating the threshold

Program for calculating the threshold for decisions of the attention and non-attention is simply designed in three pages, i.e. 1) EEG, 2) HEG, and 3) Hybrid modes (correspond to three taps selection in Fig. 8). According to Fig. 8, there are four important components of GUI.

1. Tab control for switching to another page, user can select at the top of the page to calculate the threshold of EEG and/or HEG.

2. LED buttons for start/stop of collecting of data. The first button is used for start/stop collecting the non-attention data, the second button is used for start/stop the attention data, and the third button will show the calculated threshold when clicked.

3. The display of the calculated thresholds.

4. The filled slide is used to indicate the number of acquired training data.

E. Neurofeedback program

After the threshold calculation, the calculated threshold will be automatically transferred to the neurofeedback program for controlling the game. The neurofeedback program consists of three modes as shown in Figs. 9(a)-9(c). From Figs. 9(a) and (b), the GUI of EEG neurofeedback and HEG neurofeedback consists of four parts.

1. Tab control for switching to other modes. User can select one of the three modes at the top of the page.

2. LED status, it shows the status of attention of patient. If LED is in green, patient is in the attention state. If LED is in red, patient is in the non-attention state. The goal of the patient is to hold the green LED.

3. The filled blank shows the threshold that is transferred from the previous calibration program.

4. The filled blank displays the current EEG ratio/HEG level that changed in real time.

According to Fig. 9(c), the hybrid system has the program that processes simultaneously both EEG and HEG. In this case, the patient has to hold the green LED both EEG and HEG because the output of the program is "on" when both the EEG LED and the HEG LED are green. There are six important components of this page.

1. EEG display (the blanks and the fill slides), it shows the threshold of EEG and the current EEG ratio.

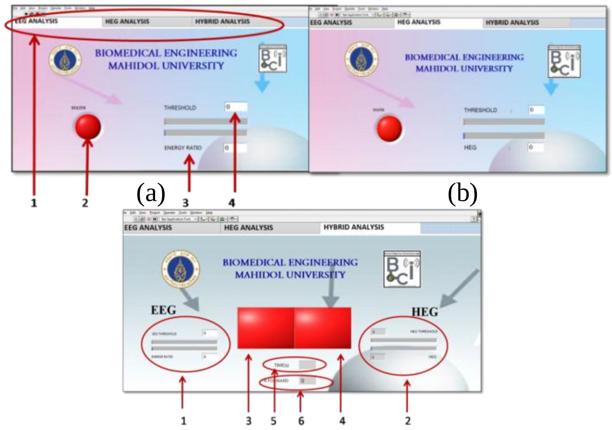
2. HEG display (the blanks and the fill slides), it shows the threshold of HEG and the current HEG level.

3. LED of EEG, it is green when EEG ratio is greater than the EEG threshold.

4. LED of HEG, it is green when HEG level is greater than the HEG threshold.

5. The filled blank shows the time of training in second.

6. The filled blank shows the percentage between the overall outputs "on" and "off" as a report for the medical doctor.



(c)

Fig. 9 GUI of neurofeedback program, (a) EEG neurofeedback, (b) HEG neurofeedback, (c) hybrid EEG-HEG neurofeedback

IV CONCLUSIONS

In this paper, we have proposed the hybrid EEG-HEG based neurofeedback device that is used for ADHD treatment. The important principle is to simultaneously employ the EEG and HEG sensors. The advantage point of this method is to reduce the weak points occurred from each sensor. The software of the hybrid EEG-HEG based neurofeedback device consist of two parts, i.e. 1) calibration program used for systematically calculating the thresholds for each patient, and 2) neurofeedback program used for the treatment. The program consists of three signal processing algorithms to process only EEG, only HEG and simultaneously process both EEG and HEG. The visual feedback game can be changed according to the recommendation of the medical doctor.

ACKNOWLEDGMENT

This work is supported by the National Research University (NRU) Funding of Mahidol University. The authors would like to thank Siriraj hospital and Yuwaprasart Waithayopathum Child Psychiartric Hospital, Thailand, for the clinical trial consulting.

REFERENCES

[1] Friel, P.N., EEG biofeedback in the treatment of attention deficit/hyperactivity disorder. Alternative Medicine Review, 2007. **12**(2): p. 146-151.

[2] Gevensleben, H., *et al*, Distinct EEG effects related to neurofeedback training in children with ADHD: A randomized controlled trial. International Journal of Psychophysiology, 2009. **74**(2): p. 149-157.

[3] Gil, Y., Li G., and Lee J., Integrated real-time neurofeedback system to raise the frontal lobe activity: design and implementation. Conf Proc IEEE Eng Med Biol Soc, 2009. **2009**: p. 845-8.

[4] Hamadicharef B., *et al*, Learning EEG-based Spectral-Spatial Patterns for Attention Level Measurement. Conf Proc IEEE ISCAS, 2009. **2009**: p. 1465-8.

[5] Blackett, G., Hemoencephalography:A New Form of Neurofeedback. York biofeedback Centre. Website address: http://www.yorkbiofeedback.co.uk

[6] Toomim, H., EEG or HEG? That is the question. Website address: http://pdfsearchpro.com/eeg-or-heg-that-is-the-question-pdf.html/

[7] Korenman, E.S., Basics of HEG Neurofeedback. 2005. Website address: http://www.psycho-neuro-feedback.com/

[8] Toomim H. *et al*, Intentional Increase of Cerebral Blood Oxygenation Using Hemoencephalography (HEG): An Efficient Brain Exercise Therapy. EEG and Director of CNRS, 2005.

[9] Toomim H. *et al*, Intentional Increase of Cerebral Blood Oxygenation Using Hemoencephalography (HEG): An Effi cient Brain Exercise Therapy. EEG and Director of CNRS, 2005.

[10] Trangkasombat, U., Clinical Characteristics of ADHD in Thai Children. J Med Assoc Thai, 2008.

[11] Kropotov, J.D., Quantitative EEG, Event-Related Potentials and Neurotherapy, ed. f. edition. 2009.