Integrated real-time neurofeedback system to raise the frontal lobe activity: Design and Implementation

Yeongjoon Gil, Gang Li and Jungtae Lee

Abstract - The anti-social behaviors of the people who are characteristic of abnormal action have seriously affected our society. Recent years, with the development of brain science, the features of human's abnormal action have been identified by means of the low frontal lobe activities. However, in many countries, the corresponding systems for identification and treatment are in an insufficient situation. Thus, in this paper, an integrated portable and real-time neurofeedback system assisted by EEG has been developed. The algorithm for this system has been developed and its performance has been verified by the fMRI experiment. Through the experiment, we ensured that the subjects controlled and checked their frontal lobe activities by themselves via the integrated real-time neurofeedback system. And then, the potential human's abnormal action could be not only early detected, but also eased via neurofeedback system. Therefore, we expected that our system can be more benefit to individuals and society.

I. INTRODUCTION

RECENT years, with the development of brain science, the features of human's abnormal action have been identified that the psychotics have very low frontal lobe activities. Their actions could have a serious impact on our society.

The cause of this psychotic can be divided into some mechanisms, such as the cause of genetic, stroma and broken connection between frontal lobe and thalamus by activities of autonomic nervous system (ANS). Now many scientists have announced that the cause of psychotics is low frontal lobe activity (FLA).

Reduced FLA can cause various forms of pathological symptoms. ADHD(Attention-Deficit Hyperactivity Disorder) is one outstanding case, and it is exhibited in a more aggressive form as psychopathology.

In the State of Oregon, U.S., 1998, a 15-year-old boy killed his parents at home, went to school and shot at teachers and students with guns. Two were killed and 25 were injured. After the incident, a psychologist named Daniel G. Amen checked the FLA of the boy and diagnosed that functioning had seriously deteriorated.

So, a treatment for enhancing FLA was given to the student, and it was noted that after the treatment, his FLA improved significantly, his temper became milder, and he eventually became another normal boy [1]. A Japanese psychologist, Mori Akio, measured the EEG of students addicted to games, and reported that among all EEG parameters associated with the frontal lobe, which indicate brain activities, the parameter of Beta(13~30Hz) waves were very low[7].

Generally, based on different frequency bands, EEG signals can be categorized into 4 specific categories of brain activity, which have been commonly discussed in EEG literature: EEG waves as shown in Table 1.

TABLE 1
Specific brainwave types and their associated state of consciousness

Brainwave Frequency	State of Consciousness
Delta (below 4Hz)	-Sleep, Unaware, Deep-Unconsciousness
Theta (4-7Hz)	-Drowsiness, Unconscious, Optimal Meditative State
Alpha (8-12Hz)	-Deeply-Relaxed, Passive-Awareness, Composed
Beta (13-30Hz)	-Fully-Awake, Alert, Excitement, Tension

In 1950, scientists thought that the cause of this psychotic is genetic. So, they gave up treatment and therapy. With the development of psychiatry, the method of therapy depended on the nerve stabilizer appears. But many scientists suspected that therapy depends on drug. In fact, if the patients depending on drug stop to take the drug, the state of illness will be worse than ever. In order to reduce this side effect, many scientists tried various therapy methods in the world. Among these therapy methods, the neurofeedback is low side effect and ratio of the recurrence [5]. But neurofeedback therapy's disadvantage is that it needs a long period of treatment and reaction ranged from 6 months to 1 year, while the therapy using drug needs a short period for reaction, ranged from 1 hour to 1 day.

In 1967, NASA, USA began research concerning neurofeedback therapy. The researchers in NASA discovered that the astronaut who got frequently smelled the fuel of the rocket engine gets the Epilepsy easily. So, they used the neurofeedback method as the therapy of the Epilepsy patients. And, in 2000, in clinical trials for the Epilepsy patients, therapy's effect using neurofeedback was improved [10].

Now, this therapy has made a great achievement in USA and UK.

In Amen Clinic Centre, California, USA, Daniel G. Amen said that the cause of human's abnormal action was the low level of FLA. And he improved the effect of neurofeedback therapy through experiment [1]. Also, this therapy improved the treatment effect of ADHD in clinical trials and Dissociative Disorder [1].

Generally, the latent period of aggressive tendency behavior which is human's abnormal action is 10 years. For example, the psychopath in teenage who had an abnormal childhood starts to commit critical crime from late 20 years old to early 30 years old. So, brain scientists said therapy and corrective training for the criminal in late 10 years old to early 20 years old is important.

So, it is necessary to develop therapy and corrective training system for human's abnormal action. Most of potential patients were not treated appropriately, therefore their symptoms got worse and if their behaviors are harmful, the impact on society is very critical.

Consequently, further research is required for the development of systems which determine the potential for abnormal actions in humans.

In this research, we introduced the integrated neurofeedback system which is able to simply determine in real-time and training for high FLA.

II. SYSTEM DESIGN

In order to measure easily, it is necessary to design a portable device (pEEG) to filter and amplifier the weak EEG signals. And the neurofeedback system which is used to make determination via analysis of EEG signal from pEEG is also necessary. Thus, we developed an integrated real-time neurofeedback system to meet the requirement mentioned above. Fig 1 shows the block and specific diagram of the proposed system.
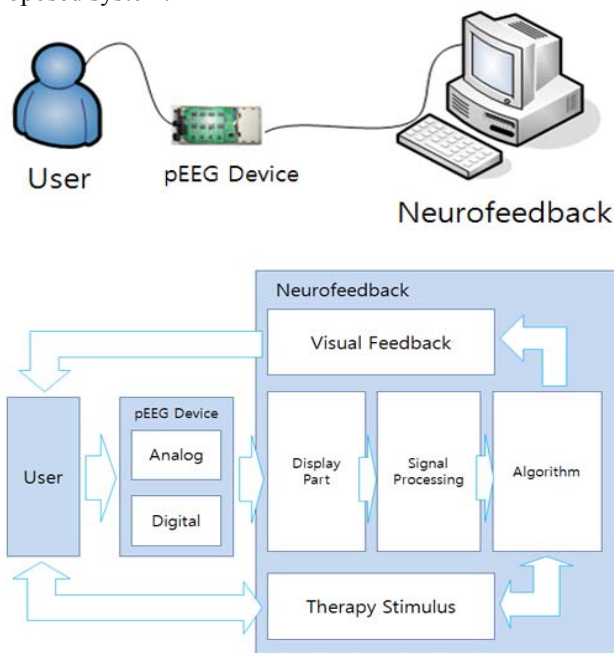

Fig 1. Structure of integrated real-time neurofeedback system

A. Structure of EEG Device

The internal structure of the pEEG device as shown in Fig 2 could be divided into analog and digital parts. The analog part is consisted of amplifiers and filters. And the digital part is mainly responsible for the digital form of analog data and appropriate format transformation which is necessary to the neurofeedback part.

The filtering range of the band-pass filter in analog part is from 0.15 to 130Hz. And a 60Hz notch filter is used to remove power line interference. The magnification of signal was set as about 20,000 times. The sampling rate adopted was 256Hz. In digital part, we used the 8051 microcontroller as the core component. This device has an 8-channel system to amplify the EEG.

B. Structure of Neurofeedback

The obtained data from pEEG was transmitted into neurofeedback part. The Fig 3 shows the concrete diagram of the neurofeedback part.
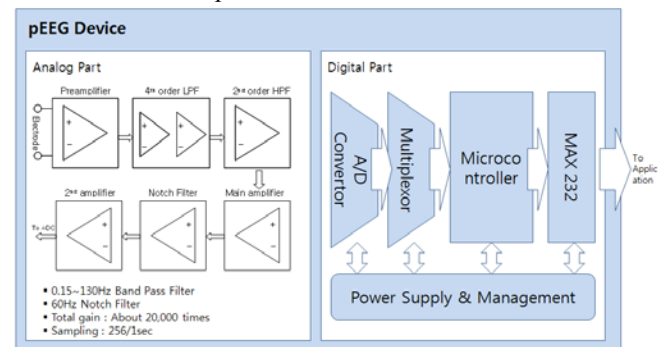

Fig 2. Internal structure of pEEG device

This part is consisted of three modules. The first one is the display module which draws the signal. The second one is the signal processing module. The last one is the determination module which depends on the algorithm to make a decision.
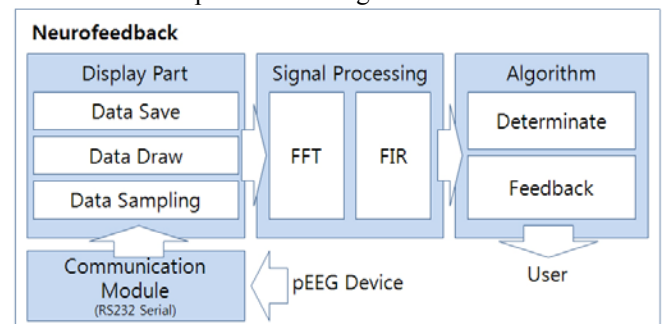

Fig 3. Internal structure of neurofeedback

Follows the name and function of the module:
1) Data Sampling: 256 sampling points per second
2) Data Draw: convert data into signal
3) Data Save: save the data
4) FIR (Finite Impulse Response): software filter (0.5~30Hz)
5) FFT (Fast Fourier Transform) : convert time domain into frequency domain
6) Determination: determination by algorithm on system

7) Feedback: visual feedback via monitor

C. Algorithm of feedback

Among all the brain structures, the frontal lobe is the most advanced, which is responsible for functions such as concentration, rational decision-making and impulse control. So when these functions are performed, the β power is high. But, it is slightly difficult to determine the FLA by only the amount of β power. The reason is that the difference of brain wave varies greatly across persons. Therefore, in this research, the discerning parameter was distinguished by the β waves exhibited by EEG, which was measured in the stable and stimulated states. The stable state is that subjects were told to close their eyes for five minutes, and their relaxed states were measured. Stimulus state is a task mode, for example puzzle game or reading book, requiring the use of the frontal lobe, involving activities such as memorizing and calculating.

In our neurofeedback system, Δβ was used as a parameter and it defined difference between the stimulus state of β Power and the stable state of β Power. Based on this result, Δβ was chosen as the parameter used for the discerning method for distinguishing subjects with reduced frontal lobe functioning. Satisfying this condition also, the ones with a lower β Power than normal in the stable state were determined as candidates for reduced frontal lobe functioning.

So, β power of subject with lower than 18% in the stable state and Δβ of subject with lower than 12% were grouped as having lower FLA than normal individuals. Fig 4 shows the flow chart of the algorithm of neurofeedback.
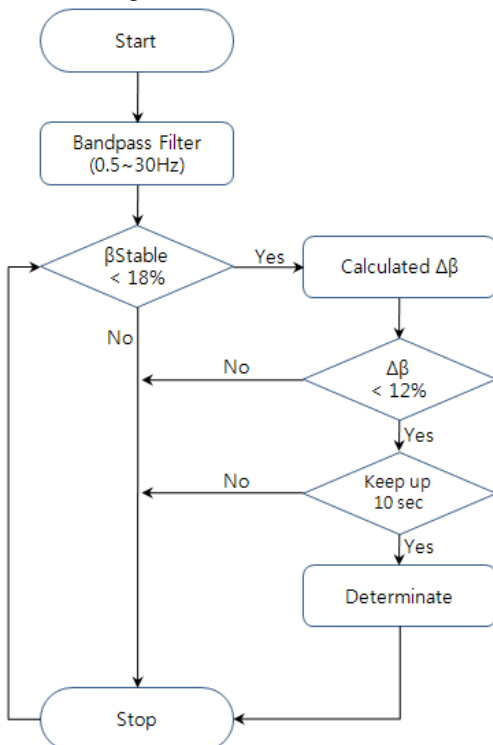

Fig 4. Flow chart of algorithm to determine

Through the experiment, the determination algorithm is not good to be applied if unchanged. Generally, the nerve cells of the brain changed many times per second. So, immediate reaction of the system is impossible. Therefore, if the same level of the β wave can be maintained for 10 seconds, our system will feedback to subject.

The users are able to check and train themselves by means of the feedback of their FLA displayed by the moving progress bar which indicates bottom of right side of Fig 5.
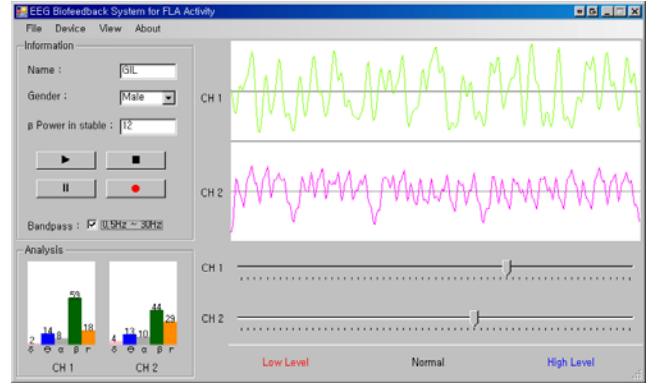

Fig 5. The display of the real-time neurofeedback system

We used the International EEG 10-20 System of electrode placement. Two coordinates were chosen and measured. FLA was measured at Fp1 and Fp2. Electrodes for the reference and ground were at A1 and Iz, respectively, at the back of neck. Ag-AgCl disc electrodes were adopted, and the sample rate was 256Hz per second. The A/D converter resolution was 12 bits.

III. IMPLEMENTATION AND EXPERIMENT RESULTS

Fig 6 is the big picture of our experiment which used the pEEG device and neurofeedback system. Fig 5 is the display of the neurofeedback. In this Fig, the real-time signal waveform and feedback of the FLA via progress bar are presented at the upper right and at the lower right respectively. And the options of band-pass filter and the analysis of the real-time brain wave by FFT is displayed at the lower left.

Fig 6 Big picture of our experiment

IV. CONCLUSION AND FUTURE WORKS

Everybody's action and thought is subjected to own will. However, due to the loss of brain function, some incorrect behaviors will happen, resulting in many disadvantages for individuals and society. Given the reason above, it is necessary to research the frontal lobe of human brain, which is responsible for the behavior control. The β power of the brain wave at the frontal lobe is relatively lower than others, when the incorrect behaviors happened. But, it is slightly difficult to determine the FLA by only the amount of β power.

Therefore, in this research, the discerning parameter was distinguished by the β waves exhibited by EEG, which was measured in the stable and stimulated states. Subjects with less than 18% β Stable and Δβ 12% were grouped as having lower FLA than normal individuals.

Our developed neurofeedback system based on this algorithm mentioned above is easy to determine who are likely to the degradation of the FLA. Also, the subjects could train for a high level activity after checked the original level of the activity by themselves in real time.

We have no therapy data from our neurofeedback system. Therefore, from now on, it is necessary for us to research the therapy deeply.

If the persons, who are likely to degrade the FLA, use our system, they will find this potential low FLA problem before it becomes too serious, and to obtain appropriate therapy. Therefore, it benefits all of society, as well as for individuals and families.

References

[1] DANIEL G.AMEN, Change Your Brain, Change Your Life: The Breakthrough Program for Conquering Anxiety, Depression, Obsessiveness, Anger, and Impulsiveness. Sanford J: Greenburger. Inc; 2000

[2] DANIEL G.AMEN , Healing the Hardware of the Soul: Enhance Your Brain to Improve Your Work, Love, and Spiritual Life. Simon & Schuster. Inc; 2002

[3] R. Thalemann, Specific Cue Reactivity on Computer Game-Related Cues in Excessive Gamers. Behavioral Neuroscience 2007; 121 (issue 3): 614-618.

[4] Thompson M. Thompson L. The Neurofeedback Book, AAPB, 2003.

[5] Thompson M, Thompson L. Neurofeedback for Stress Management. Chapter in Lehrer, Woolfolk and Sime (Eds.) Principles and Practice of Stress Management 3rd Edition: Guilford Publications; 2004

[6] Joel F. Lubar, Discourse on the development of EEG diagnostics and biofeedback for attention-deficit/hyperactivity disorders. Applied Psychophysiology and Biofeedback 1991, 16(Number 3): 201-225

[7] Mori Akio, Video game "brain damage" claim criticised. NHN; 2001

[8] LIU Mingyu, WANG jue, YAN Nan, YANG Qin. Development of EEG Biofeedback System Based on Virtual Reality Environment. Engineering in Medicine and Biology 27th Annual Conference 2005, 1: 5362-5364, 2005

[9] Joel F. Lubar. Discourse on the development of EEG diagnostics and biofeedback for attention-deficit/hyperactivity disorders. Applied Psychophysiology and Biofeedback 1991; 16, 3: 201-225.

[10] Comparison of EEG correlates of reinforcement, internal inhibition and sleep. Roth, S.R., Sterman, M.B. and Clemente, C.D. ; Electroenceph. Clin. Neurophysiol. 23:509-520, 1967.

[11] Toshio Kobayashi. Analysis of the human sleep electroencephalogram by the correlation dimension. Psychiatry and clinical neurosciences 2000, 54: 278-279.

[12] A. Das. Applicability of Lyapunov Exponent in EEG data analysis. Complexity International 2002; 9(das01): 1~8.

[13] C. Yamaguchi. Wavelet analysis of normal and epileptic EEG. Proceedings of the Second Joint EMBS/BMES conference 2002; 96-97.

[14] Maarten-Jan Hoeve et al. Detecting Epileptic Seizure Activity in the EEG by Independent Component Analysis. ProRISC Workshop on Circuits, Systems and Signal Processing 2003; 373-382.

[15] D.L. Hudson et al. Diagnostic Implications of EEG Analysis in patients with Dementia. Neural Engineering, 2nd International IEEE EMBS Conference 2005; 629- 632.

[16] Nikos K. Logothetis. Neurophysiological investigation of the basis of the fMRI signal. Nature 2001, 412: 150-157.

[17] Peter J. Lang. Emotional arousal and activation of the visual cortex: An fMRI analysis. Psychophysiology 2003; 35(Issue 2): 199 – 210, 2003.

[18] Stephen M. Smith. Advances in functional and structural MR image analysis and implementation as FSL. NeuroImage 2004, 23(Supplement 1): 208-219.

[19] Mitsuo Takeda, Hideki Ina, and Seiji Kobayashi. Fourier-transform method of fringe-pattern analysis for computer-based topography and interferometry. JOSA 1981; 72(Issue 1): 156-160.

[20] Chenheifeng, Jungtae Lee. Development of a Portable EEG Monitoring System based on WLAN. Proceedings of 2007 IEEE International Conference on Networking, Sensing and Control 2007; 460-465.

[21] Burkett, V. Shannon; Cummins, John M.; Dickson, Robert M. Effects of neurotherapy on attention and impulsivity in crack cocaine addiction: A controlled, single-blind study. Journal of Neurotherapy, Vol 8(2), 2004. pp. 119-120.

[22] Saxby E, Peniston EG. J Clin. Alpha-theta brainwave neurofeedback training: an effective treatment for male and female alcoholics with depressive symptoms. Psychol. 1995 Sep;51(5):685-93.