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# Implementation of Multi-adaptive Filter for EOG Removal and Biofeedback Output Controller

Bo Sep Ahn†, Pil Un Kim††, Jin Ho Cho†††, Myoung Nam Kim††††

## ABSTRACT

In this paper, a multi-adaptive filter is proposed for removing EOG and the 60 Hz power supply noise from EEG measured in the frontal lobe and the feedback output control method is implemented for biofeedback. The multi-adaptive filter has been implemented on the TMS320C6711 DSP system and the feedback output control algorithm has been realized by calculating the ratio of alpha wave on the TMS320C31 DSP system with real time performance. Through the experiment using the implemented multi-adaptive filter and feedback output controller, we demonstrate that the proposed adaptive filter effectively removes EOG and the 60 Hz power supply noise from the measured EEG in the frontal lobe and the feedback algorithm controls the level of stimulation by the ratio of the alpha wave.

**Keywords** : Multi-adaptive filter, EOG, EEG, biofeedback

## 1. INTRODUCTION

The brain waves (electroencephalogram, EEG) have been extensively researched and many devices about them have been developed in the field of psychoanalysis, diagnosis, and treatment. One of these equipments, portable EEG biofeedback device analyzes EEG and it leads the subjects into the stable state to relax themselves by audible, visual, and tactile stimulations.[1,2] Usually, EEG is affected by the variation of external environment, contact status and the position of electrodes. But one of these effects, the highest distortion to the EEG is made by electroocculogram (EOG), the signal being generated from eye blinks and movements. So, when measuring EEG, EOG makes a large amount of drifts on EEG signal. In common portable EEG biofeedback systems, positions of electrodes are close to the eyes of subject, so the acquired EEG signal includes EOG inevitably. Therefore, it is necessary that a real time pure EEG extraction from distorted EEG for an accurate EEG analysis and proper biofeedback ratio to the subject. One of a various kind of EOG removal methods, adaptive filter method is known as a suitable way of real time filtering measurement on DSP hardware. In this paper, we proposed multi-adaptive filter based on adaptive noise canceller (ANC) and adaptive line enhancer (ALE) as a external noise-including EOG and power line interference of EEG-removal method[3,4]. The proposed adaptive filter has been implemented on the TMS320C6711 DSP system, and feedback output control algorithm has been implemented on the TMS320C31 DSP

※ Corresponding Author : Myoung Nam Kim, Address : (700-422) 101, Dongin-2Ga, Chung-Gu, Daegu, Korea, TEL : +82-53-420-5266, FAX : +82-53-420-5264
E-mail : kimmn@knu.ac.kr
Receipt date: May 17, 2004, Approval date: Sep. 1, 2004
† School of Electrical Engineering and Computer Science, Kyungpook National Univ.
(E-mail : anhbo2510@hotmail.com)
†† Dept. of Medical & Biological Eng., Graduate School, Kyungpook National Univ.
(E-mail : zeros97@hanmail.net)
††† Dept. of Biomedical Eng., School of Medicine, Kyungpook National Univ.
(E-mail : jhcho@ee.knu.ac.kr)
†††† Dept. of Biomedical Eng., School of Medicine, Kyungpook National Univ.
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system for calculating a level of stimulation. After the ratio of alpha wave been calculated by the fast fourier transform (FFT) analysis from the extracted EEG signal, feedback level could be determined simultaneously. From these experimental results, we confirmed that multi-adaptive filter can effectively remove EOG signal from EEG signal which is measured on the frontal lobe and feedback output control algorithm can produce a proper level of stimulation according to the ratio of alpha wave.

## 2. THE PROPOSED MULTI-ADAPTIVE FILTER SYSTEM FOR EOG REMOVAL

Adaptive filters generally make the desired output signal using the adaptive learning method. There are many adaptive algorithms such as LMS and RLS. The RLS algorithm takes a longer time for operating than LMS algorithm does. Whereas, the convergence speed of RLS is faster than that of LMS[4,5]. ANC and ALE can be constructed by LMS or RLS algorithm respectively. For improving signal-to-noise ratio, the ANC uses one input and reference signal for noise removal and the ALE makes the use of one input signal and delayed input signal. The ALE structure has some advantages for the multi-channel realization since there is no need for the reference signal. The ANC requires a desired signal as a reference for removing EOG in the frontal lobe. However, by the use of practical EEG amplifying system, it is difficult to measure only the desired signals such as a pure EEG or EOG data in the frontal lobe. Thus, the ALE structure is adopted as the front part of multi-adaptive filter so that the filter can predict reference signal to remove EOG[6,7].

The structure of proposed multi-adaptive filter for the portable biofeedback system is shown in Fig. 1. The proposed multi-adaptive filter adopts the ALE structure based on LMS algorithm as a front part. In the proposed multi-adaptive filter structure, the ALE performs the EOG prediction for the reference signal of ANC from the measured EEG and the ANC improves the performance of EOG removal using RLS algorithm at a latter part of the multi-adaptive filter. Since the output of ALE contains mainly EOG component and applies to the reference of ANC, the ANC predicts the purified EOG component from the measured EEG data affected by EOG signal.

The power line hum and body noise are removed by the additional digital notch filter after analog preprocessing. The multi-adaptive filter has a transversal filter structure for the upgrade of weighting factors as shown in Fig. 1.[7,8]. Numerical formulas used in Fig. 1 are as the followings.

$$y_1(n) = \hat{w}^H x(n) \tag{1}$$

$$e_1(n) = x(n) - y_1(n) \tag{2}$$

$$\hat{w}_1(n+1) = \hat{w}_1(n) + \mu x(n) e_1(n) \tag{3}$$

Eq. (1), (2) and (3) formulas are describing the LMS algorithm. $\mu$ is a step-size parameter and $w$ is a tap-weight vector.

$$k(n) = \frac{\lambda^{-1} P(n-1) x(n)}{1 + \lambda^{-1} x^H(n) P(n-1) x(n)} \tag{4}$$

$$e_2(n) = y_1(n) - y_2(n) \tag{5}$$

$$\hat{w}_2(n+1) = \hat{w}_2(n) + k(n) e_2(n) \tag{6}$$

$$P(n) = \lambda^{-1} P(n-1) - \lambda^{-1} k(n) x^H(n) P(n-1) \tag{7}$$

Eq. (4), (5), (6) and (7) summarize RLS algorithm. $k(n)$ is a gain vector, $\lambda$ is an exponential weighting factor, and $P(n)$ is an inverse correlation matrix. The numerical formula about the last output of multi-adaptive filter is eq. (8).

$$y(n) = x(n) - y_2(n) \tag{8}$$

## 3. IMPLEMENTATION OF MULTI-ADAPTIVE FILTER ON DSK6711 SYSTEM

The proposed multi-adaptive filter algorithm has been developed in TMS320C6711 DSP system with real-time processing[9]. The block diagram

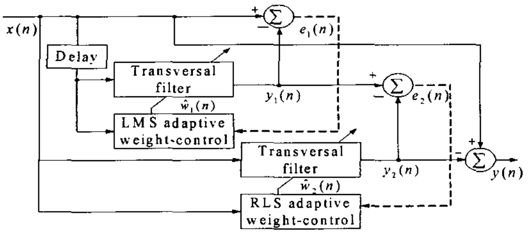


Fig. 1. Block diagram of the multi-adaptive filter.

implemented on DSP system is shown in Fig. 2. The EEG in the frontal lobe is measured by analog preamplifier, analog filter and digitized at a 1 kHz sampling rate by the 16 bit A/D converter on TMS320C6711 DSP system. The analog filter is the 4-th order filtering circuit. Also, these filtering circuits are designed by considering the frequency range of the EEG signal, 3-30Hz. For the digitized EEG data, the proposed multi-adaptive filter algorithm removes EOG component. The result of filter is transferred to the feedback output controller based on TMS320C31 DSP system. Through a

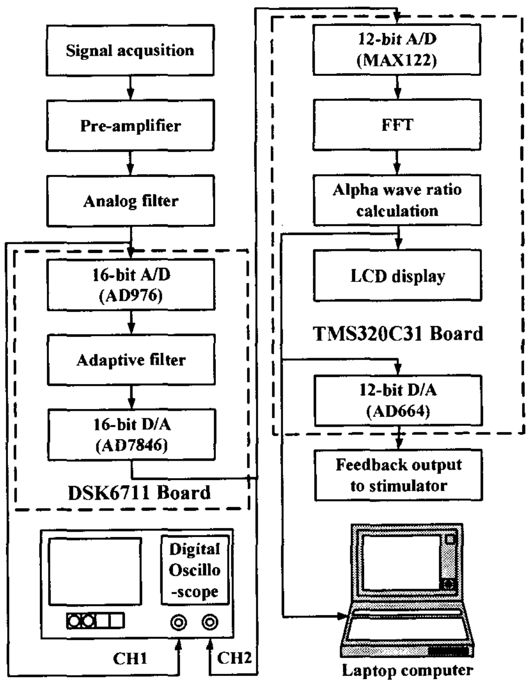


Fig. 2. Block diagram of the portable EEG biofeedback system.

16bit D/A converter on TMS320C6711 DSP system, the results are converted into analog values and can be observed by the digital oscilloscope. The pure EEG component is processed by the proposed multi-adaptive filter is sampled at 128 Hz, 12 bit A/D converter of TMS320C31 DSP on the latter part of total system. The ratio of alpha wave is calculated through the FFT and the result controls the output level of 12 bit D/A converter for the input signal of visual, tactile, and auditory stimulator. The LMS adaptive algorithm for ALE is described in Fig. 3. RLS algorithm can be explained by a little modification of Fig. 3 as described in eq. (4), (5), (6), and (7). The RLS adaptive algorithm for ANC is described in Fig. 4.

## 4. EEG FEEDBACK CONTROL ON DSP SYSTEM

The block diagram of feedback output control algorithm is shown in Fig. 5. This algorithm calculates the frequency characteristics of the EEG data using FFT and then produces the ratio of alpha wave in the whole brain waves on the TMS320C31 DSP system. According to the ratio of alpha wave, the feedback quantities of 3 stimulators are determined.

## 5. SIMULATION AND EXPERIMENTAL RESULT

### 5.1 Experiment for Multi-Adaptive Filter

The proposed multi-adaptive filter has been demonstrated through computer simulation and experiment for EOG removal from the measured EEG. The pure EOG signal is purposely created to simulate and used as a reference signal of multi-adaptive filter for performance evaluation. The EOG is the aperiodic waves and has the various amplitudes. The pure EEG is acquired in frontal lobe by the conventional EEG acquisition

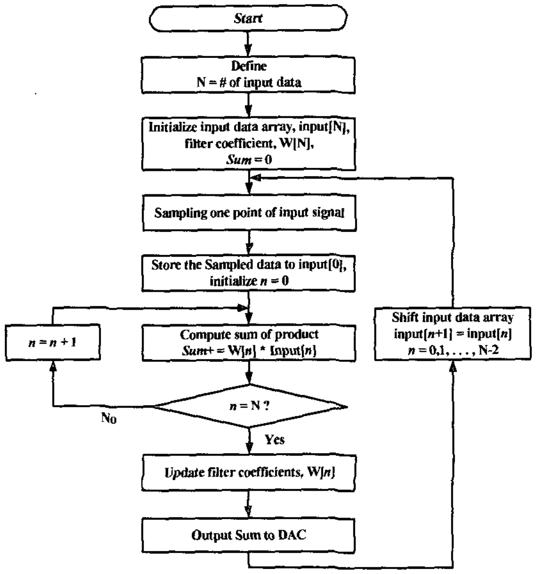


Fig. 3. Flowchart of the LMS adaptive filter algorithm.

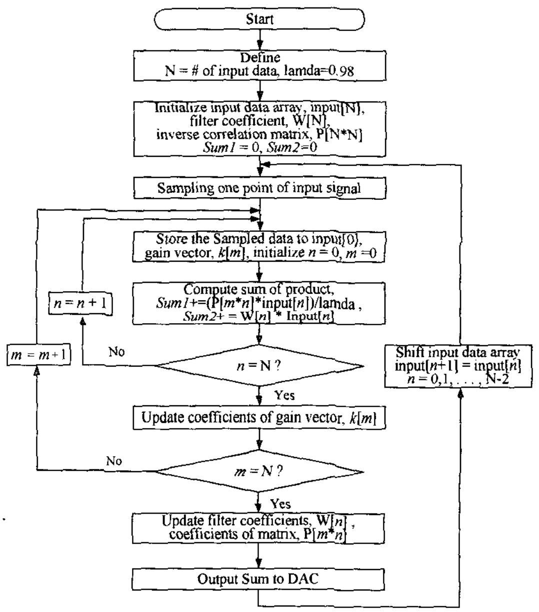


Fig. 4. Flowchart of the RLS adaptive filter algorithm.

system when a subject do not move eyeball intentionally. For the performance evaluation of common adaptive noise cancellers, LMS, RLS, and QR-RLS adaptive canceller has been simulated and compared

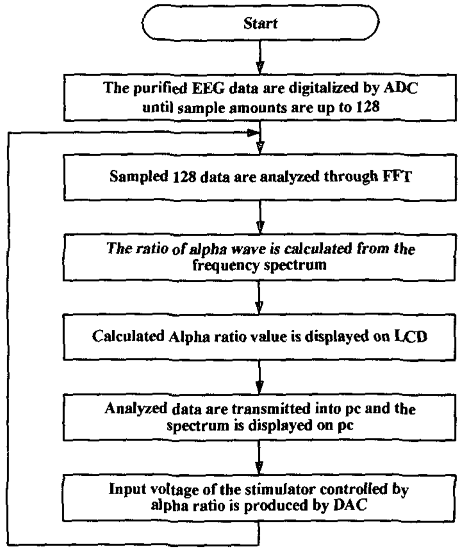


Fig. 5. Block diagram of the feedback output control algorithm.

with each other. As shown in Table 1, RLS canceller has good signal to noise ratio (SNR) and preferable mean square error (MSE) and proper operation time for real-time filtering. The QR-RLS takes the longest operation time on simulation process any others. Therefore, RLS canceller has been selected for the latter part of the multi-adaptive filter.

Input signal of the proposed multi-adaptive filter is Fig. 6.(a) and the output waveform is Fig. 6.(b). From the Fig. 6, it is verified that the proposed multi-adaptive filter can effectively remove EOG component. The proposed multi-adaptive filter has been compared with the LMS adaptive enhancer filter.

Table 1. The performance comparison with adaptive canceller algorithms

| | Operation time (sec) | Normalized correlation coefficient | SNR (dB) | MSE |
|---|---|---|---|---|
| LMS canceller | 0.172 | 0.9558 | 10.46 | $6.92\times10^{-3}$ |
| RLS canceller | 0.593 | 0.9713 | 12.37 | $2.19\times10^{-3}$ |
| QR-RLS canceller | 1.250 | 0.9765 | 12.79 | $1.97\times10^{-3}$ |

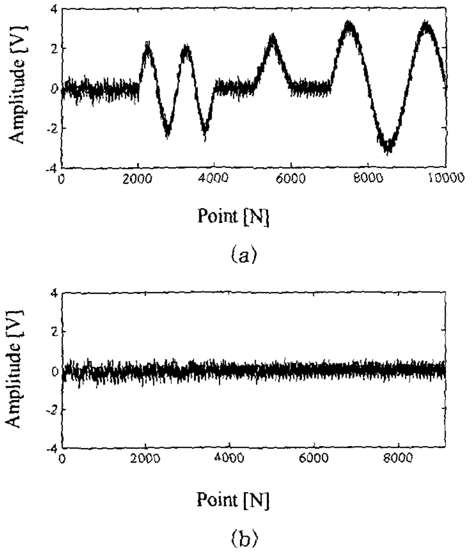


Fig. 6. The result of simulation for the multi-adaptive filter : (a) simulated input waveform and (b) output waveform.

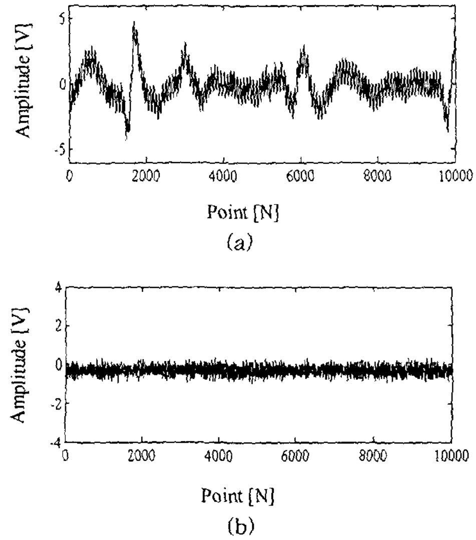


Fig. 7. The real time processed EEG on the TMS320C6711 DSP system : (a) input waveform and (b) output waveform.

The result of comparison with the proposed multi-adaptive filter and the LMS adaptive enhancer filter is in Table 2. The results show that the proposed multi-adaptive filter has better SNR than LMS adaptive enhancer does. The verified multi-adaptive filter has been implemented and experimented on the TMS320C6711 system with real-time processing. The results are shown in Fig. 7. Fig. 7.(a) is input waveform and (b) is output waveform of the multi-adaptive filter.

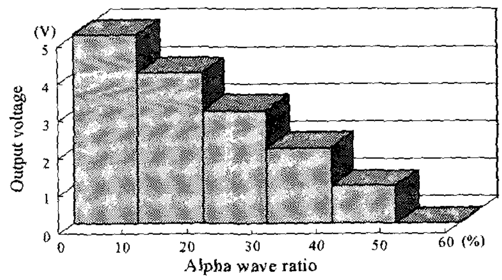


Fig. 8. The feedback value of the output control algorithm.

Table 2. The efficiency improvement of multi-adaptive filter

| | Operation time (sec) | Normalized correlation coefficient | SNR (dB) |
|---|---|---|---|
| Noisy signal | 0.172 | 0.0364 | -16.43 |
| LMS enhancer | 0.156 | 0.8488 | 4.84 |
| Multi-adaptive filter | 0.579 | 0.8542 | 5.53 |

### 5.2 Experiment for Feedback Output Controller

According to the ratio of the alpha wave, in Fig. 8, the feedback output controller outputs appropriate input voltage of stimulator part in the portable biofeedback system through D/A converter.

The experiment for verifying the performance of feedback output controller has been performed on DSP system and the results are shown in Fig. 9. The EEG data were measured for 4 men in the *frontal* lobe when they closed their eyes for 20 seconds and processed by the multi-adaptive filter using TMS320C6711 system. The pure EEG data were sampled at 128 Hz by 12 bit A/D converter

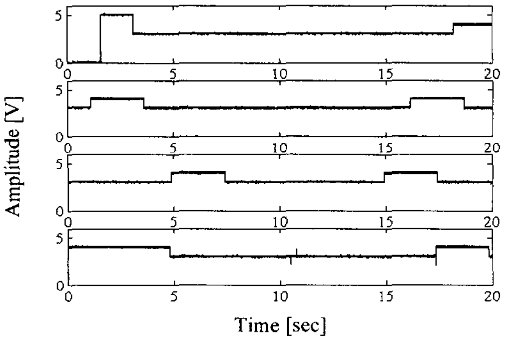


Fig. 9. The results of the feedback output controller.

and calculated by FFT on TMS320C31 DSP system. We confirmed that the feedback output voltage was changed according to the change of alpha wave ratio on TMS320C31 system with real time processing. And also the result show that 4 men have the alpha wave ratio of 10~30%, because feedback voltages are 3~4[V] at normal states.

## 6. CONCLUSION

The EEG measured in the frontal lobe is greatly distorted by electro-occulogram (EOG) which is generated from eye blink and movement. In common biofeedback systems, the acquired EEG in the frontal lobe inevitably includes EOG since the electrodes are localized at the frontal lobe close to eyes for subjects convenience. In this paper, the multi-adaptive filter using ANC and ALE has been proposed and implemented on TMS320C6711 system for EOG removal without a reference signal. And the feedback control algorithm has been realized by FFT and calculation of the ratio of the alpha wave on TMS320C31 system. Through the simulation and experiment results, the proposed multi-adaptive filter has been demonstrated to efficiently remove EOG. In case of measuring EEG in frontal lobe that use proposed multi-adaptive filter, we can remove distortion of EEG affected by EOG. The portable biofeedback output controller generate the proper amount of stimulation by the ratio of alpha wave and this can lead patient in a mental stable state. In the near future, this system can be used as clinical application for mental disease diagnosis and treatment.

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**Bo Sep Ahn**

He received his B.S. and M.S. degree in School of Electronic and Electrical Engineering from Kyungpook National University, Daegu, Korea, in 2002 and 2004, respectively. He is currently working for research engineer in LG Electronics. His interests are the design of adaptive filter and EEG signal analysis in Medical Engineering.

**Pil Un Kim**

He received his B.S. degree in Computer engineering from Kyungwoon University and the M.S. degree in Medical and Biological engineering from Kyungpook National University, Korea in 2001 and 2003, respectively. At present, he is in a Ph.D. degree course of the same university of his M.D. degree course. His research interests include the object detection and extraction in medical digital image, biomedical signal analysis using processor, and CAD(Computer Aided Diagnosis).

**Jin Ho Cho**

He received his B.S. degree in Electrical Engineering, in 1977, M.S. and Ph.D. in Electronics from Kyungpook National University, Daegu, Korea, in 1979 and 1988, respectively. He is currently Chief Professor of Biomedical Engineering at Kyungpook National University, a Professor in the School of Electrical Engineering & Computer Science and a Director of the Advanced Research Center of Recovery of Human Sensibility. His research interests include the biomedical signal processing, sensor applications, and biomedical instrumentations.

**Myoung Nam Kim**

He received his BS, M.S. and Ph.D. degree in electronics from Kyungpook National University in 1987, 1989 and 1994 respectively. He is currently an Associate Professor at Department of Biomedical Engineering, Kyungpook National University, Daegu, Korea. His research interests include medical image processing, biomedical signal analysis, biological modeling, and biomedical electronics. He has been especially active in medical signal analysis and has developed new methods for electroencephalogram.