BMFLC adaptive filter for detecting SSVEP in noisy EEG recordings

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***Abstract*— Low-cost BCI systems often display poor SNR thus introducing a need for further signal conditioning. This paper presents a BMFLC (Band-limited Multiple Fourier Linear Combiner) adaptive filter for isolating a SSVEP waveform from EEG signals with power line interference and other artifacts.**

I. Introduction

Electroencephalography (EEG) is a procedure that records electric signals at different parts of the scalp. It has numerous applications such as epilepsy monitoring, determining brain damage and Brain-Computer Interfaces (BCI). The signals of interest are in the 0.5 – 50 Hz frequency band and have 0.1 to 100 μV amplitude [1]. Low-cost BCI systems are more susceptible to noise and artifacts than conventional EEG systems. DSP algorithms can be used to address these problems and export features of interest. [2] have tested the Fourier Linear Combiner (FLC) for EEG signal extraction, however, it does not allow for frequency-varying signal tracking as required when extracting Steady State Visual Evoked Potentials (SSVEP). This paper applies the BMFLC approach, introduced in [3], to the extraction of SSVEP for the first time, showing robust extraction even in the presence of recording noise.

II. Methods and Materials

An EEG system was developed using a 24-bit ADC from TI (ADS1299). The signals were acquired using an ATmega2560 microcontroller at 250Hz sampling rate and transferred to a computer via Bluetooth connection. The system was powered from a 5V battery to ensure electrical isolation and safety of the test subjects. Ag/AgCl wet passive electrodes were connected to the inputs of the ADC using unshielded cables.

The BMFLC uses the Least-Mean-Squares algorithm to create an estimate $\hat{\mathbf{x}}$ of the SSVEP waveform from the input EEG signal $\mathbf{y}$. For this application the BMFLC is given by:

$$x_{rk} = \sin\left(2\pi\left(f_0+\frac{r}{G}\right)k\right)+\cos\left(2\pi\left(f_0+\frac{r}{G}\right)k\right), \quad 0 \le r \le 9 \quad (1)$$

$$\varepsilon_k = y_k - \mathbf{w}_k{}^T\mathbf{x}_k = y_k - \hat{\mathbf{x}}_k, \quad (2)$$

$$\mathbf{w}_{k+1} = \mathbf{w}_k + 2\mu\varepsilon_k\mathbf{x}_k, \quad (3)$$

where $\mathbf{x}$ is the SSVEP model, $\mathbf{w}$ is the amplitude weights vector, f_0 is the starting frequency, G = 50, μ = 0.00001. This results in a frequency resolution of 0.02Hz which means that even slight deviation of the SSVEP frequency, for example due to monitor refresh rate, can be accounted for.

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The SSVEP experiment was conducted by placing the EEG electrodes on the Fz-A1 points. The test subject was asked to look at a computer screen at a ~30cm distance. A red screen was flashing for 5 s at 5Hz and was stationary for further 5 s afterwards. The experiment was repeated at 5.9Hz. 10 measurements were performed to guarantee consistency – no substantial deviations were found.

III. Results

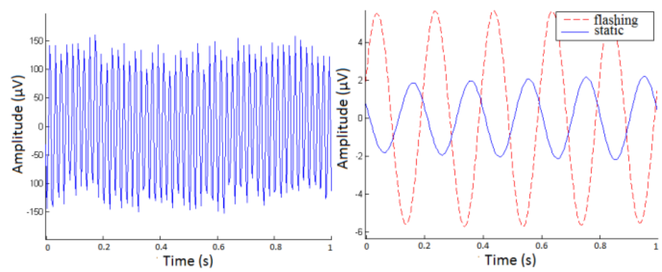

Figure 1. Typical unfiltered signal from the low-cost BCI system (left). Extracted 5Hz signals using BMFLC (right).

The performance of the filter to extract 5 Hz signals from noisy EEG recordings is shown in Fig 1. On the right, an increase of the signal amplitude when the subject is looking at a flashing screen can be observed. In order to quantify the changes in the signals, we calculated power spectral density in the bands of interest. For the 5 Hz SSVEP experiment the average increase in power is 346% and for the 5.9 Hz SSVEP it is 292%.

IV. Analysis and Conclusions

The results from these experiments suggest that BMFLC can be an efficient way to extract information from noisy EEG recordings. The benefits of the BMFLC in comparison to standard DSP techniques are low computational requirements and ability to operate in real time due to the zero phase lag [3]. BCI applications based on this low-cost EEG system and BMFLC algorithm can aid paralyzed patients to control their wheelchair [4] or patients with ALS/locked in syndrome to communicate more efficiently.

References

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