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An EEG device with synchronization of auditory stimuli

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Abstract

In this paper, a simple method is proposed for alignment of EEG signals and auditory stimuli. In typical event-related potential (ERP) studies, hardware or software synchronization is used to provide the event synchronization of auditory stimuli, which is not a perfect real-time synchronization. In this study, an EEG signal acquisition frontend is used for simultaneous measurement of EEG signals and auditory stimuli. Experiments are conducted to verify the electrical performance of the proposed method. Experimental esults show that EEG signals are captured in a synchronized method to auditory stimuli while maintaining high quality electrical performance.

Keywords: electroencephalography, auditory evoked potential, acquisition device

1. Introduction

Electroencephalography (EEG) is a medical imaging technique that measures the electrical activities of the brain. It is a reliable tool to monitor abnormal and normal brain activities from newborns to adults. Due to its non-invasive nature, it could be applied repeatedly to subjects virtually without any risks or limitations. Thus, EEG has been widely used in different areas such as medical diagnosis, clinical studies and physiological research [1-4]. The voltage change generated by the brain from response to an external stimulus is known as evoked potential (EP). However, auditory evoked potential (AEP) is the electrical signal elicited from the brain that follows the auditory stimulus in a time-locked manner. It is characterized by the positive and negative deflections of the EEG amplitude and the latency with temporal reference to the stimulus onset [5-6]. However, AEP is much smaller amplitude than the background noise of EEG, therefore their activities could not be clearly displayed on the raw EEG traces [7]. In order to extract the AEP signal, it is necessary to average individual responses to a large number of identical stimuli. The spontaneous background EEG components such as noise are averaged out, leaving the time-locked AEP standing out from the background [5,7]. Therefore, it is crucial for the EEG data acquisition system to be capable of registering accurate stimulus onset such that the averaging is done on the same timing window [9].

In general, there are two types of event synchronization in EEG system: hardware synchronization and software synchronization. A physical wire is used to connect the stimulation device to the EEG system in hardware synchronization. This stimulation device is typically comprised of a computer with a physical interface such as parallel port and behavioral experiment software. The EEG recording device detects the trigger through the cable and EEG signals from electrodes synchronously to establish the beginning of the stimulus, thus setting the temporal reference to measure EP latencies [10]. However, there is limitation in hardware synchronization since it requires the stimulation device to output a trigger at a physical port, which causes an extra delay due to execution of physical hardware and application software. In software synchronization, the connection between stimulation software and recording software is utilized to mark the event. One of the state-of-the-art solutions handling the real time EEG synchronization is Lab Streaming Layer (LSL) [11]. It is an open source data acquisition project that relies on clock offset measurements to handle event information and timing [12]. Software synchronization requires reliable and timely transmission of data packets, which is also a challenge to avoid extra delay in the application software. In this paper, a simple and real-time EEG signal synchronization method has been proposed to align EEG signals and auditory stimuli.

2. Methodology

In Fig. 1, an audio driver is connected to the computer to receive auditory stimuli from computer and then splits it into two paths. This driver could be the sound card integrated in the computer itself. One of outputs is sent to the speakers of headphone to present stimuli to the subject, while the other output is connected to the EEG device and it is recorded synchronously with the EEG signals. As the auditory stimuli are sent through two paths simultaneously, the stimuli are delivered at the EEG device and the speakers at the same time. Since auditory stimulus is transmitted as an electrical signal, it could be recorded by the EEG data acquisition unit in EEG device which is normally a low-noise programmable analog-to-digital converter (ADC). The signal is then shown in the EEG recording software in computer together with other EEG signals. Therefore, the stimulus onset could be established. This eliminates any needs of hardware or software synchronization and simplifies connection in the EEG system.

Two experiments were designed to verify the proposed synchronization method. The first experiment was the signal quality test, in which the frequency response and total harmonic distortion plus noise (THD+N) were evaluated. In this experiment, analog sinusoidal signals were generated at 13 different frequencies in the range of 2 Hz – 8000 Hz by a waveform generator. This frequency range is enough to synchronize to the EEG signals and find the position of stimulus. In each frequency, the signal was scaled by a signal attenuation circuit shown in Fig. 2 which is typical inverting amplifier op-amp circuit. The signal is then attenuated to 100 μVpp at the output and recorded in 10 seconds by EEG device. The 10- second interval was chosen because it was used in the ADS1299 manual for noise measurement [13]. The ratio of the noise component and the recorded data was then used to calculate the THD+N. In the second experiment, a known EEG dataset from subjects performing auditory task was obtained from the EEGLAB database [14]. First 10 seconds of EEG signals from 5 electrode positions (Fpz, Fz, Cz, Pz and T7) were extracted and converted to analog signals by the waveform generator. This experiment aims to simulate the setting of direct recording of the EEG signals and auditory stimulus simultaneously. In Fig. 3, a computer was used as stimulation device for the source of auditory stimulation, while the waveform generator was simulated as the source of the known EEG signals from the subject. Both signals were attenuated to order of microvolts by individual signal attenuation circuit in Fig. 2 and then recorded by the EEG device. The input signal was measured by an oscilloscope for result comparison. In the postprocessing stage, all signals were filtered by a 50 Hz notch filter. The EEG signals were filtered additionally by a 70 Hz low-pass filter and downsampled to 200 samples per second (sps) to facilitate fair comparison with the input signals from the waveform generator.

3. Implementation

The Texas Instruments ADS1299EEG-FE evaluation board was used as EEG device in this verification [15], in which the ADS1299 mainboard is connected to the MMB0 motherboard to allow data transmission from the ADS1299 chipset to computer through the USB port. Fig. 4 shows the photo of the evaluation board used in this experiment. This ADS1299 chipset is common low-noise programmable ADC for biopotential measurement applications [15-16]. Its low noise, low power consumption and low cost characteristics have made it suitable to be used in multiple EEG hardware and software studies [15-19]. In addition, it has sampling rate up to 16000 sps, which is suitable for direct recording of auditory stimuli compared to other ADC devices. The eight simultaneous-sampling channels with individual programmable gain amplifier and dedicated reference and bias electrode with a small form factor makes it suitable for this study. The experimental results of two experiments are shown in following section.

4. Experimental Result

Fig. 5 shows the frequency response of all channels from 2 Hz to 8000 Hz. It shows a flat response in the frequency range below 1000 Hz which is within in the region of 0.1 dB and is closest to 0 dB at 1000 Hz. Above 1000 Hz, the frequency response begins to fall below 0 dB due to the insufficient sampling rate for the input signals and reaches to -3 dB near 3600 Hz. As most EEG signals are in the low frequency range (0.1 Hz to 30 Hz), the device is capable of acquiring reliable EEG signals. This response is sufficient enough for synchronization in this case. If complete recording of auditory stimuli is needed, there is a limit of maximum frequency at 1000 Hz.

In THD+N measurement, the result is shown in Fig. 6. The results of all channels obtained are below -55 dB in frequency range between 2 Hz and 1000 Hz. In particular, in the range of 2 Hz to 100 Hz, most channels are below -60 dB. The performance of THD+N could be optimized depending on the sampling frequency needed for acquiring auditory stimuli. In EEG applications, sampling rates up to 1000 Hz are more than enough to record precise EEG signals [16]. A signal with 1000 Hz was used as audio sound in the second experiment. This sinusoidal signal is used for simulation of incoming auditory stimuli. Fig. 7 and 8 show the captured known EEG signals simultaneously with 1000 Hz sinusoidal signal and their respective error distribution. The recorded EEG signals were compared to the raw input EEG signals to evaluate the system accuracy. The average error is 0.87 μV with a standard deviation of 1.23 μV. The results of all signals are shown in Table 1. In above two experiments, these indicate that it is possible for the EEG device to capture EEG signals and auditory stimuli in a synchronized method while maintaining high quality electrical performance.

5. Conclusion

This study proposed a simple method for synchronization of EEG signals and auditory stimuli. The method is evaluated by the ADS1299EEG-FE evaluation board with two experiments. The results demonstrate that the proposed method is able to measure the signals in a time-locked method, with a flat frequency response in typical EEG signal range. The quality of EEG signals could be further optimized by the sampling rate used for recording audio signal.

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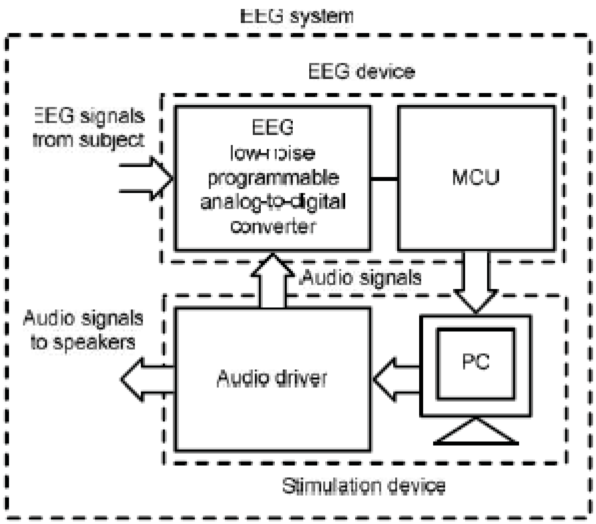

Fig. 1 *The EEG device with proposed synchronization method*

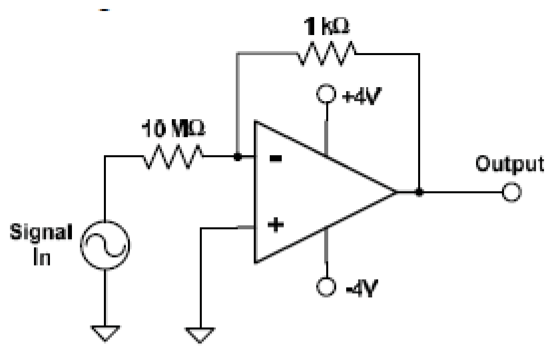

Fig. 2 *Signal attenuation circuit*

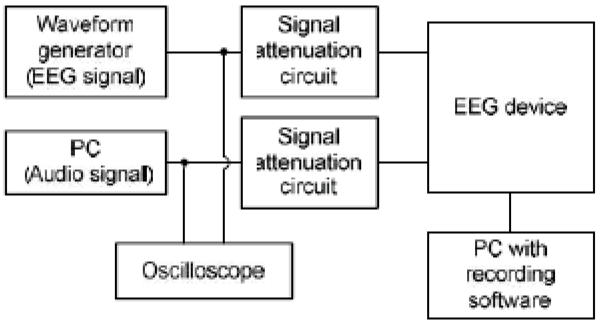

Fig. 3 *Block diagram of the experiment setup of second experiment*

Fig. 4 *Photo of the ADS1299EEG-FE evaluation board*

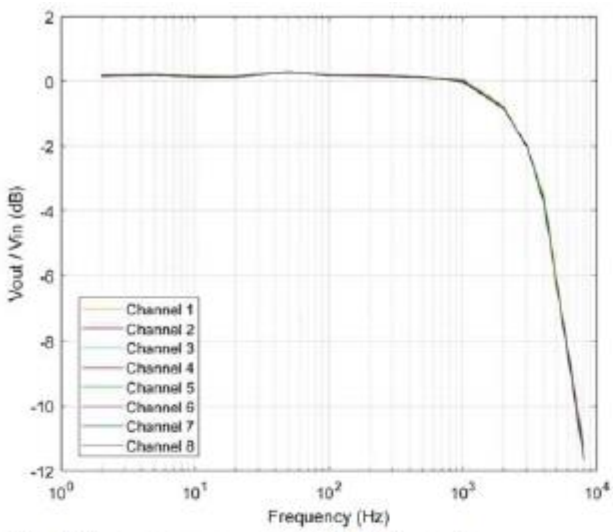

Fig. 5 *Frequency response of all channels*

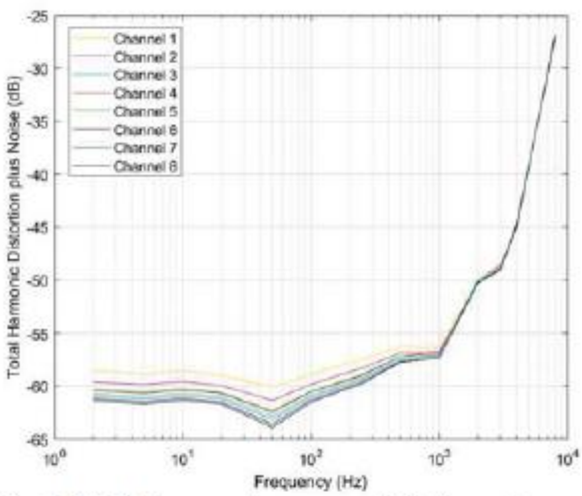

Fig. 6 *THD+N versus frequency of all channels*

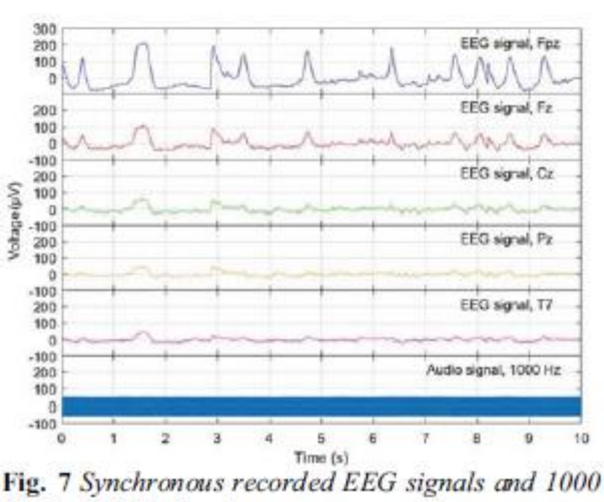

Fig. 7 *Synchronous recorded EEG signals and 1000 Hz sinusoidal signal*

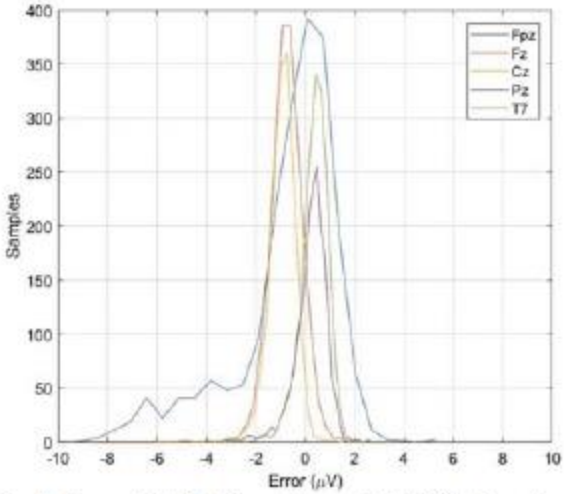

Fig. 8 *Error distribution of recorded EEG signals*

Table 1 *Average error and standard deviation of the EEG signals*

EEG signal	Average Error (μV)	Standard deviation (μV)
Fpz	1.47	2.14
Fz	0.84	0.67
Cz	0.94	0.55
Pz	0.55	0.66
T7	0.55	0.56