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Reduction of the power line interference in a single-channel AEP recording system based on low cost consumer electronics: application for dissemination of audiology concepts in schools and at a science museum.

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In this poster we describe our progress with the development of a modular, low-cost, flexible, and high quality AEP recording systems based on consumer electronics. We have identified the power line interference (PLI) as the main limitation for many AEP recording systems and we have proposed a simple and effective algorithm for PLI reduction. Thanks to this algorithm, we have proposed a very simple AEP recording system based on low-cost consumer electronics, easy to be replicated from the components, appropriate for research, education and dissemination purposes. In this poster we describe the algorithm for PLI reduction, the AEP recording system, and some dissemination activities including demonstrations based on this system, recently carried out in our area.

Background

Two years ago, in the IERASG-2023 conference at Cologne, we presented a modular AEP recording system, including a live demonstration during the sessions. This system was mostly based on consumer electronics (microphone preamplifier, headphones, USB audio interface).

The main problem to be solved was the PLI noise, and in order to deal with this problem we recorded independently the common-mode component and the differential component, and assuming that the common-mode component contains no biological signal, a subtraction of of the common-mode component (with appropriate weights based on statistics) provided a very reasonable reduction of the PLI.

This approach required some specific hardware (a passive box with just some resistors in order to prepare the differential and the common-mode components in separate channels) and 2 input channels (one for the differential and the other for the common mode), i.e. two microphone preamplifiers and an audio interface with two inputs (the description of this system is available at our web).

Today, two years later, we present an advanced and flexible AEP recording system, totally based on consumer electronics (no specific hardware) thanks to a new algorithm for PLI reduction.

Methods

Advanced method for PLI reduction: The method for PLI reduction is relatively simple to be understood. The underlying problem of the power line interference is the frequency drift of the mains frequency. The nominal frequency is 60 Hz in USA or 50 in Europe, but this frequency fluctuates in order to accommodate the imbalance between the power production and the power demand (when the demand exceeds the production, the frequency drops until the control mechanisms increase the production, and vice versa). Most methods for PLI reduction are complicated and inefficient due to this frequency drift. It is interesting to note that the frequency drift is consequence of the changes in the rotational speed of the power generators, and is associated to a time drift. For this reason, the frequency drift is proportional to the frequency (the frequency shift at each harmonic is proportional to the index of the harmonic).

The proposed method includes the following steps: Firstly the time drift is estimated from one harmonic. Then the time drift is compensated (by resampling the recorded signal with a compensation of the time drift). After this time drift compensation, the frequency drift is canceled. And after the frequency drift cancellation, the PLI reduction is really easy. Details are available in an article recently published (and there is also a related patent under evaluation).

Figure about the PLI reduction procedure: The figure illustrates, with an ECG signal, the proposed PLI reduction procedure. We can see an ECG signal severely affected by PLI (the signal, a detail of the signal, with the P-QRS-T components and the 50 Hz PLI oscillation). We can see also the power spectral density, with several harmonics (at 50, 100, 150, 200 Hz, etc.). If we see a detail of the harmonics we can appreciate the effect of the frequency drift: on one hand they the spectral power is spread around the nominal frequency; on the other hand, the peak is shifted with respect to the nominal frequency. It is interesting to note that the frequency shift is proportional to the harmonic index (because the frequency shift is a consequence of a time drift).

Removing the PLI is difficult due to the frequency drift (adaptive filters should be applied to accommodate the frequency shift; narrow notch filters are not efficient because they do not cancel the PLI properly; wide notch filters cancel the PLI but they causes a large distortion). Removing the PLI is easy after the frequency drift cancellation (because in this situation, the PLI spectral power is concentrated at the nominal frequency of the harmonics).

After the frequency drift cancellation, the method removes the harmonics. Finally the algorithm transforms the clean signal to the original time scale (by applying the inverse of the time drift compensation). In the ECG example, after the method for PLI reduction, we can see the ECG signal, a detail where the P-QRS-T components are clearly appreciated, and the power spectral density without the PLI harmonics.

New concept of biopotential recording system: Thanks to the PLI reduction, the design of a biopotential recording system is easier: solutions like driven right leg circuit or battery powered recording system with optical or radio decoupling are not necessary. This simplifies the electronic design of the recording system. We have designed a biopotential recording system based on off-the-shelf consumer electronics, with no specific hardware, and only requiring one input channel. This allows a low cost solution, with a system design appropriate for research, education or dissemination purposes, providing good quality of the recorded responses.

Figure of the biopotential recording system: The diagram represents the elements of the proposed biopotential recording system. It includes the electrodes, a microphone preamplifier (this model costs about 80 Euros), an audio interface for synchronous stimulation and recording (about 180 Euros this model, used for education or dissemination activities), a computer (for preparing the stimulation and processing the acquired biopotentials), and the headphones (to provide audio stimulation to the participant). The audio interface is powered with a battery, and the USB connection to the computer is isolated with an USB isolator, in order to provide electrical isolation between the participant and plugged components (i.e. the computer, sometimes also a video-projector). The picture shows the different components of the biopotential recording system.

Dissemination workshop: Using this concept of biopotential recording system, we have prepared a workshop with three demo activities, related to ECG and AEPs. We start with ECG because this signal is usually better known, and this biopotential is easy to be acquired and observed in real time. Regarding auditory evoked potentials, we have prepared two demos, one of them using clicks, the other using synthetic phonemes as stimuli.

During the spring/summer of 2025, we have performed several demonstrations and outreach events for primary and secondary schools, university engineering studies, and for a science museum.

Results

From the technological point of view, the method for reduction of the PLI is very efficient. In order to evaluate the method, we have compared three situations: (1) the raw signal affected by PLI, i.e. without any PLI reduction method; (2) the signal obtained after applying a conventional PLI reduction based on notch comb filter (without time drift compensation); and (3) the signal provided by the proposed PLI reduction based on notch comb filter applied after the time drift compensation. We have compared the effect of the PLI reduction method for ECG signals and for AEP responses.

Figure of the PLI reduction results: In the left side of the figure, a portion of ECG is compared for the three situations: without PLI reduction (top), with conventional notch comb filter (center) and with notch comb filter with time drift compensation (bottom). In the right side, AEP responses to clicks of different stimulation levels are represented: without PLI reduction (top), with conventional notch comb filter (center) and with notch comb filter including time drift compensation (bottom). The responses are represented for a portion of latency appropriate for ABR (latency axis in linear scale, range between 0 and 20 ms) and for ABR+MLR (latency axis in logarithmic scale, range between 0.5 and 200 ms).

In both cases (ECG and AEP responses) an improvement is derived from the application of the conventional PLI reduction method. The application of the proposed method for PLI reduction provides a significant improvement with respect to the conventional method (and of course, also with respect to the original recorded signal).

Figure of demo screenshots: For the dissemination workshop, based on the PLI reduction method and the biopotential recording system, we have developed three protocols (one for ECG and two for AEPs) oriented to demonstrations and outreach activities.

ECG demo: The ECG demo represents in real time the ECG signal in one panel. Based on a heart-beat detection/synchronization procedure, a second plot superimposes the last detected heart beat (in black) and some previous ones (in red) synchronized in the center of the window, allowing an intuitive perception of the changes in the heart rate and a detailed representation of the ECG signal and the components. A third plot represents the heart rate and the average hear rate as a function of time (also updated in real time), and finally, some numbers about the experiment are presented (total time of the recording, heart rate, and some statistics of the heart rate). During the demo, the sound of the signal recorded by the electrodes is sent to an audio amplifier (allowing the audience to hear the signal in real time). The participant is asked to make some movements of the arms (generating a lot of miogenic activity which can be observed in the plots and can also be heard by the audience). The heart beats are observed and also the ECG signal (and the heart beats) can be heard by the audience. The participant is asked to make some movements in order to increase the heart rate, and then to sit down and relax in order to see the heart rate decrease. Finally the participant is asked to breath profoundly and relax in order to see the predominance of the parasympathetic nervous system, observed as large oscillations of the heart rate.

AEP demo using clicks: The demo of AEPs using clicks provides click stimuli of different levels between 40 and 70 dB NHL at average rate of 44.4 Hz (ISI between 15 and 30 ms). The stimuli are presented in portions of 15 seconds. The EEG signal and the power spectral density are represented in real time. Every segment of 15 seconds, the responses are estimated from the EEG by applying the multi-response deconvolution, and the responses are represented in two panels: one of them for ABR (latency in linear scale, range 0-20 ms), the other for ABR+MLR (latency in logarithmic scale, range 0.5-200 ms). During the demo, the participant is asked to blink his/her eyes and to make facial movements, in order to allow the audience to see the miogenic noise, and to aware the participant about the importance of reduce the miogenic activity. The stimulation is also sent to the audio amplifier in order to provide a sample of the audio to the audience. The protocol is explained and it is remarked the low amplitude of the responses (compared to the ECG signal) and the importance of averaging, silence of the audience, and being patient in order to record during several minutes, while the responses are updated every 15 seconds. Once the instructions are clearly understood, the recording protocol starts again, the responses are progressively updated. When the recording procedure ends, the waves are discussed.

AEP demo using synthetic phonemes: The third demo include AEPs elicited with synthetic phonemes. Four different stimulation patterns are included in this test: three synthetic phonemes (/a/, /i/ and /s/) and also a burst of clicks (which, compared with the others, sounds like a raspberry blow). The vowels and the click burst are composed of short events (corresponding to the glottal pulses in the case of the vowels of the clicks in the case of the click burst). We have estimated the responses to the short events (clicks or glottal pulses) for these patterns (/a/, /i/ and click burst), and responses to the long events (phonemes or burst) for all of them (/a/, /i/, /s/ or burst). The responses to the short events include the ABR and MLR components (responses obtained for a latency range 0.5-200 ms). The responses to the long events include also cortical responses (latency range 0.1-1000 ms). The demo, as the previous one, provides a real-time representation of the EEG and the spectrum, and the responses to the short and long events, updated after each segment of 15 seconds.

Dissemination activities performed during spring 2025: At the moment of the poster preparation, three dissemination workshops with demonstration were presented: (1) for high school students, with 3 performances, (2) for telecommunication engineering students, with one performance, and (3) for primary school students, with 3 performances. In all the cases the audience found the experience interesting and informative. Most of the public had never heard about AEPs before and found very interesting to see experiments showing the electrical activity of the heart, or the neural activity associated to the hearing process.

Conclusions

The PLI reduction procedure has allowed the design of a biopotential recording system based on consumer electronics. This conception provides a robust, flexible, low-cost and open system, appropriate for research, education and dissemination purposes. The experiments show the quality of the responses acquired with this biopotential recording system, and its utility for ECG and AEP experiments out of the laboratory.

The experience with these dissemination activities including demonstrations shows that, based on this conception of biopotential recording system, it is possible to transfer, under an experimental perspective, the basic concepts of audiology and evoked potentials to the society, and particularly to students of primary and secondary school, or to university students. The workshop has attracted the interest in the educative community and in the science museum of Granada (Parque de las Ciencias).