A new approach to adaptive noise cancellation in synthetic auditory evoked potentials

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Abstract— **This paper presents a new approach for enhancing Auditory Evoked Potentials (AEP). In this study, we first generated synthetic single trial AEP data at some specified noise levels by using gamma-tone function technique and then applied the proposed Lyapunov theory based filter to the noisy AEP synthetic data. Simulation results have been demonstrated that enhanced AEP with LST based adaptive filter can effectively be used to cancel out background EEG noise for a better measurement.**

I. Introduction

Auditory evoked potential (AEP) is a bioelectric signal which is the combination of the brain electrical activity that occurs after synchronously eliciting the ear by guided sounds [1]. For obtaining AEP, the classical ensemble averaging (EA) technique is widely used and it is an acquisition method for extracting AEP from noisy data by averaging a large number of single trials [2]. But, obtained AEP includes some meaningless noisy patterns. Some techniques for denoising AEP are developed to escape these noisy patterns [3,4]. Quiroga et al [3] have proposed a wavelet based approach for analysis the single trials by reducing noise. In this study, we have proposed a new approach to enhance AEP signal by using adaptive noise cancelling algorithm based on Lyapunov stability theory (LST). AEP signal is indeed composed three types of responses which are short, middle and long latencies. Here, we have first generated synthetic AEP signals and then applied the proposed filter to the signals. The simulation results showed that the proposed algorithm can effectively be used for noise cancellation in AEP. It should be notice that the used data are synthetic AEP data, so the real data applications in clinics should be studied for further usage in future.

II. Lyapunov Stability Theory Based Adaptive Noise Cancelling Algorithm

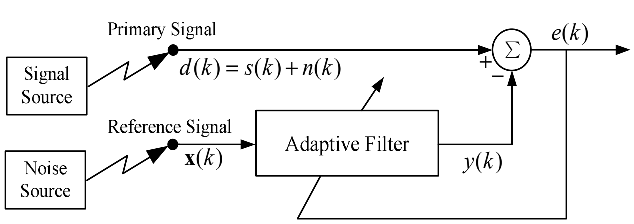

Fig. 1. Block diagram of the adaptive noise canceller

The typical structure of the adaptive noise canceller is shown in Fig.1. The primary signal $d(k)$ occurs from the model

$$d(k) = s(n) + n(k) \tag{1}$$

where $d(k)$ represents the raw AEP recordings, which is composed of the AEP signal $s(k)$ and the uncorrelated noise $n(k)$. The reference signal $\mathbf{x}(k)$ which is uncorrelated with signal $s(k)$, but correlated with the noise $n(k)$.

$$\mathbf{x}(k) = [x(k), x(k-1), \ldots, x(k-M+1)]^T \tag{2}$$

The output error of the ANC is defined in (3).

$$e(k) = d(k) - y(k) \tag{3}$$

where the FIR filter output $y(k)$ is defined in (4).

$$y(k) = \mathbf{x}(k)^T \mathbf{w}(k) \tag{4}$$

where $\mathbf{w}(k)$ is the weight vector of the adaptive filter. The weight vector update law of the LST based algorithm with step size is given in (5) [5].

$$\mathbf{w}(k) = \mathbf{w}(k-1) + \mathbf{g}(k)\alpha(k) \tag{5}$$

where the adaptation gain $\mathbf{g}(k)$ and the priori estimation error $\alpha(k)$ are defined as

$$\alpha(k) = d(k) - \mathbf{x}(k)^T \mathbf{w}(k-1) \tag{6}$$

$$\mathbf{g}(k) = \mu \frac{\mathbf{x}(k)}{\lambda + \left\|\mathbf{x}(k)\right\|^2} \left(1 - \kappa \frac{\left|e(k-1)\right|}{\lambda + \left|\alpha(k)\right|}\right) \tag{7}$$

where $0 \leq \kappa < 1$ and μ is the step size parameter that controls the speed of convergence and tracking ability of the LST based adaptive filter algorithm. Also, λ is small positive constant to avoid singularity.

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Algorithm:

Parameters:

- M = filter order
- $0 \le \kappa < 1$
- $\lambda \ll 1$ and $\lambda \in \mathbb{R}^{+}$

Initialization:

- $\mathbf{w}(0) = \mathbf{0}$

Given Data:

- $\{\mathbf{x}_k, \mathbf{d}_k\}_{k=0}^{K-1}$

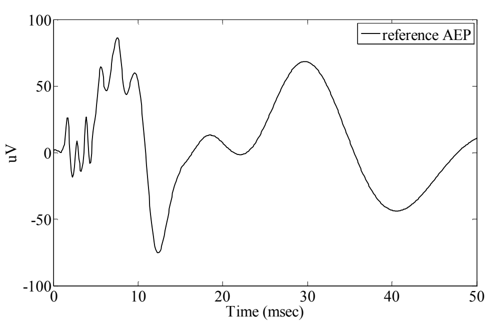
where $\mathbf{x}_k$ is the reference signal and $\mathbf{d}_k$ is the primary signal.

Computation:

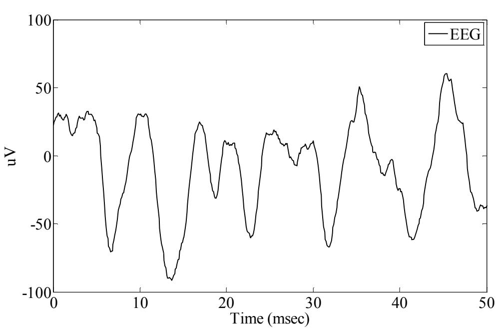
- $\alpha(k) = d(k) - \mathbf{x}(k)^T \mathbf{w}(k-1)$
- $\mathbf{g}(k) = \mu \dfrac{\mathbf{x}(k)}{\lambda + \|\mathbf{x}(k)\|^2} \left(1 - \kappa \dfrac{|e(k-1)|}{\lambda + |\alpha(k)|} \right)$
- $\mathbf{w}(k) = \mathbf{w}(k-1) + \mathbf{g}(k)\alpha(k)$
- $y(k) = \mathbf{x}(k)^T \mathbf{w}(k)$
- $e(k) = d(k) - y(k)$

III. AEP DATA

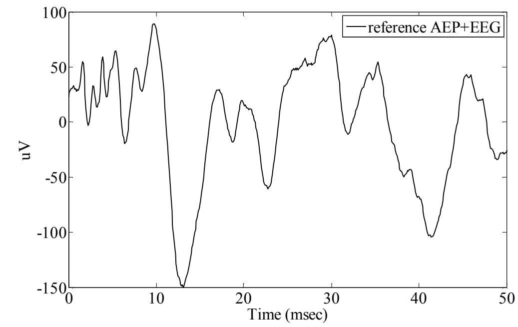
In our previous study [6], we have designed an artificial single trial AEP signal generator which generates single trial AEPs at any arbitrary SNR levels. In this study, the AEP patterns were generated for noise cancellation applications.



(a)



(b)



(c)

Fig. 2 (a) Reference AEP (b) background EEG with -5 dB white noise (c) sum of reference AEP and noise

The noisy AEP Fig. 2(c) in database were obtained by summing the generated "reference AEP" pattern Fig. 2(a) and background EEG signal Fig. 2(b) obtained using autoregressive (AR) process [6, 7]. All these implementations are formulated as in (8) and (9).

$$\textit{Single Trial AEP}(k) = AEP(k) + EEG(k) \tag{8}$$

where EEG is obtained using fourth order AR process as seen in (9) [8];

$$\begin{aligned} EEG_i(k) &= 1.508 EEG_i(k-1) - 0.1587 EEG_i(k-2) \\ &- 0.3109 EEG_i(k-3) - 0.0510 EEG_i(k-4) + v(k) \end{aligned} \tag{9}$$

where $v(k)$ represents white noise. EEG noise is generated at different noise levels for evaluation of the proposed algorithm's performance.

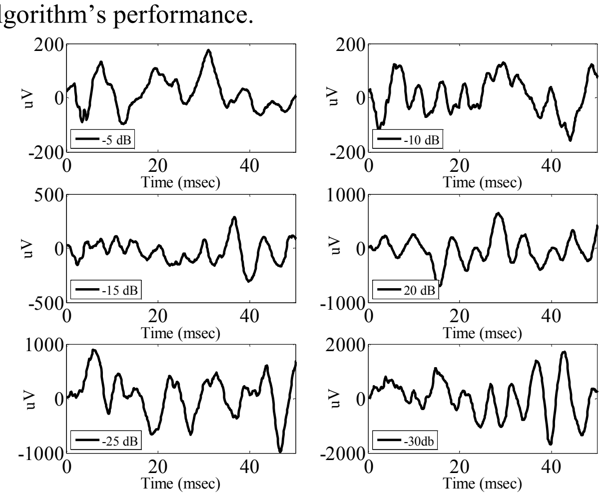


Fig. 3. Examples of the single trial AEP signals generated at -5dB, -10dB, -15dB, -20dB, -25dB, -30dB noise levels

Fig. 3 shows examples of the single trial noisy AEP signals at different noise level.

IV. SIMULATION RESULTS

In this study, all simulations are performed by using MATLAB software on a PC computer with the speed of 2.53 GHz. In simulations, we have used the following FIR linear combiner for the purpose of evaluating the performance of the proposed LST based filtering algorithm. The filter order N is selected as 5 and λ is chosen as 10^{-3}. Also the step size μ and κ are chosen as 0.005 and 0.1, respectively for all simulation examples. We have performed the proposed algorithm for synthetic AEP data obtained with 64 single trials and analyzed the results in terms of MSE (dB). The MSE (dB) is formulated as in (10) as follows;

$$MSE(dB) = 10\log\left[\frac{1}{K}\sum_{i=1}^{K}(dAEP - rAEP)^2\right] \quad (10)$$

where K is the length of AEP signal vector, *dAEP* is denoised AEP data vector and *rAEP* is the reference AEP vector.

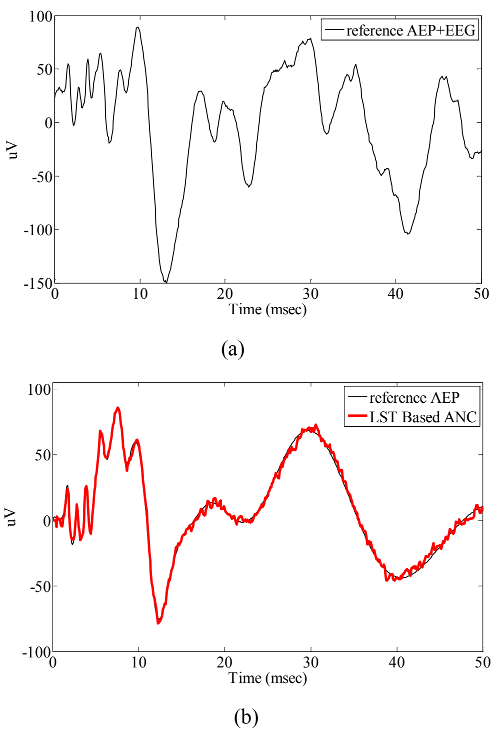


Fig. 4. (a) noisy AEP signal (b)Tracking performance of the proposed LST based ANC algorithm with 64 single trial number at -5 dB SNR.

Fig. 4(b) shows the tracking performance of the proposed LST based algorithm. As seen from Fig. 4(b), the filtering of raw AEP signal is reduced the noise and proposed algorithm converges to the reference AEP signal obtained by averaging 64 single trials. The smoothness and similarity of the measured AEP signal is very important for morphological evaluation of AEP signal in clinical studies.

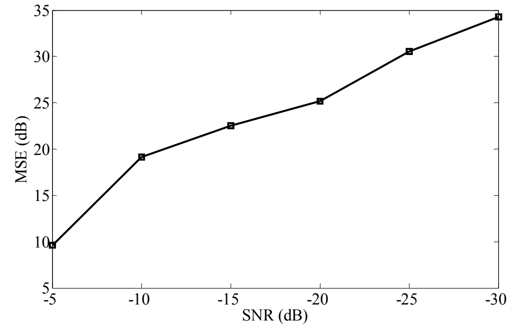


Fig. 5. Performance of the proposed LST based ANC algorithm with 64 single trial number versus different noise levels.

As seen from the Fig. 5 and its legends; as the SNR (dB) of AEP data decrease, the MSE (dB) of enhanced AEP data increase. Although real AEP measurements' noise level is generally at about -10 dB, we simulated the synthetic AEP data at the noise levels up to -30 dB level with 5dB steps for a detail analysis.

V. CONCLUSION

In conclusion, adaptive noise cancellation in single trial AEP contributes to obtain an enhanced AEP signal patterns. Although EA technique is classical and widely used technique in clinical applications, the proposed noise cancellation method can be used for measuring better AEP signals. After a lot of clinical experiments and real data usage, the proposed noise cancellation algorithm can be used in measuring every type of evoked signals. It can be our future study.

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