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NOISE SUPPRESSION IN UNSHIELDED MAGNETOCARDIOGRAPHY: LEAST-MEAN SQUARED ALGORITHM VERSUS GENETIC ALGORITHM

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ABSTRACT

This paper discusses adaptive noise cancellation in magnetocardiographic systems within unshielded environment using two algorithms, namely, the Least-Mean Squared (LMS) algorithm and the Genetic Algorithm (GA). Simulation results show that the GA algorithm outperforms the LMS algorithm in extracting a weak heart signal from a much-stronger magnetic noise, with a signal-to-noise ratio (SNR) of -35.8 dB. The GA algorithm displays an improvement in SNR of 37.4 dB and completely suppressing the noise sources at 60Hz and at low frequencies; while the LMS algorithm exhibits an improvement in SNR of 33 dB and noisier spectrum at low frequencies. The GA algorithm is shown to be able to recover a heart signal with the QRS and T features being easily extracted. On the other hand, the LMS algorithm can also recover the input signal, however, with a lower SNR improvement and noisy QRS complex and T wave.

INTRODUCTION

The human heart is made of conductive tissues that produce both an electric field and a magnetic field, depending on cardiac activity. Measuring the electric and/or magnetic fields enables various heart parameters as well as diseases to be diagnosed, such as heart beat rate and

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arrhythmia. Electrocardiography (ECG) enables the detection of heart-generated electric fields through electrodes placed on the surface of the human body. However, magnetocardiography (MCG) has been shown to be more accurate than electrocardiography for the (i) diagnosis of atrial and ventricular hypertrophy, (ii) non-invasive location of the heart's conduction pathways, (iii) the identification of spatial current dispersion patterns, and (iv) the detection of circular vortex currents which give no ECG signal [1]. Cardiac magnetic fields surround the human body and are typically very low in magnitude (about 100 pT [2]), necessitating the use of a high-sensitivity magnetometer to measure them. Furthermore, the environmental electromagnetic noise is typically much higher (in the order of 1 nT) than the heart-generated magnetic field, resulting in an extremely low signal-to-noise ratio, if patients are examined outside a magnetic shielded room.

In this paper, we adopt the concept of adaptive noise cancellation shown in Fig. 1, and use two potential adaptive signal processing algorithms, namely the Least-Mean Squared (LMS) algorithm and the Genetic Algorithm (GA) and compare their capabilities in minimizing the mean-squared of the error signal $e(k)$ and improving the SNR performance. With respect to the LMS algorithm, the GA provides additional benefits, including (i) ability to perform parallel search for population points rather than for a single point, thus avoiding to fall into local minima; (ii) no prior information on the gradient of the signal is needed; (iii) the use of probabilistic rules instead of deterministic ones, thus ensuring the convergence to an optimum solution.

ADAPTIVE NOISE CANCELLER

Adaptive noise suppression techniques are typically based on adaptive filtering. To suppress the noise, a reference input signal is required, which is typically derived from one or more magnetic sensors placed at positions where the noise level is higher than the signal amplitude. Figure 1 shows a block diagram of an adaptive noise canceller. The primary input to the canceller, denoted $d(k)$, is the sum of the signal of interest $s(k)$ and the noise $n(k)$, which is typically uncorrelated with $s(k)$. The reference input signal of the system, $x(k) = n1(k)$, is a noise signal that is correlated in some unknown way with $n(k)$, but uncorrelated with the signal of interest $s(k)$. As shown in Fig. 1, $n1(k)$ is adaptively filtered to produce a replica of the noise $n(k)$ that can be subtracted from the primary input to eventually produce an output signal $e(k)$ equals to $s(k)$.

The objective of the noise canceller is to minimize the mean-squared error between the primary input signal, $d(k)$, and the output of the filter, $y(k)$. It is noticed from [3] that the mean-squared error (MSE) is minimum when $n(k) = y(k)$, and hence, the output signal $e(k)$ is equal to the desired signal $s(k)$.

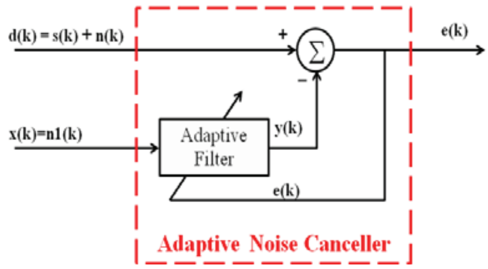

Fig. 1: Typical Block Diagram of an Adaptive Noise Canceller

The LMS algorithm aims to minimize the mean-squared error by calculating the gradient of the squared-error with respect to the coefficients of the filter. Assuming that the adaptive filter is a FIR filter of order *M,* the updating procedure is applied on coefficients b_i following the following rule [4]:

$$b_i^{(k+1)} = b_i^{(k)} + 2\mu e(k) x(k-i) \quad \text{... (1)}$$

where $i = 0,1, \ldots, M-1$, k is the iteration index and *m* is the step size that indicates the adaption rate of the algorithm and is usually included in the range (0,1].

Genetic Algorithms (GA) are part of the Evolutionary Algorithms, which are stochastic, population-based techniques inspired by the natural evolution process [5]. Using GA, the optimal solution is found through the minimization of a defined function, called the fitness function. For the problem of magnetic noise cancellation, the objective of the optimization process is to minimize the MSE.

SIMULATIONS RESULTS AND DISCUSSION

A measured cardiac signal taken from the MIT-BIH Arrhythmia Database (220.dat file) [6] was used to verify the ability of both LMS and GA algorithms to extract heart signals from noisy measured cardiac signals. This signal was captured by electrodes placed on the surface of a patient chest. The magnetic field and the electric field generated by human heart have similar waveforms[7]; therefore, it is possible to assume that the measured MCG signal has similar shape as the measured ECG signal but with amplitude of 100pT. Figure 2 (a) shows the heart signal with the typical cardiac features, namely, P wave, QRS complex and T wave, which correspond to atrial depolarization, ventricular depolarization and ventricular repolarization, respectively. Figure 2 (b) shows the cardiac spectrum that is mainly spread over low frequencies. The environmental magnetic noise was measured in our laboratory. The measured magnetic noise was more than 10 times higher than the heart signal, resulting in a signal-to-noise ratio (SNR) of -35.8 dB. The environmental magnetic noise was added to the heart signal to produce the input signal of the noise canceller. This signal is shown in Fig. 2 (c) and (d). It is noticed that the heart spectrum was completely encircled by the noise;

particularly strong noise peaks were exhibited at dc and 50 Hz whereas the other dominant peaks at the 60 Hz, 100 Hz and 150 Hz had lower levels. The environmental magnetic noise was linearly filtered to produce a correlated noise which was used as the reference signal input to the noise canceller, as illustrated in Fig. 1.

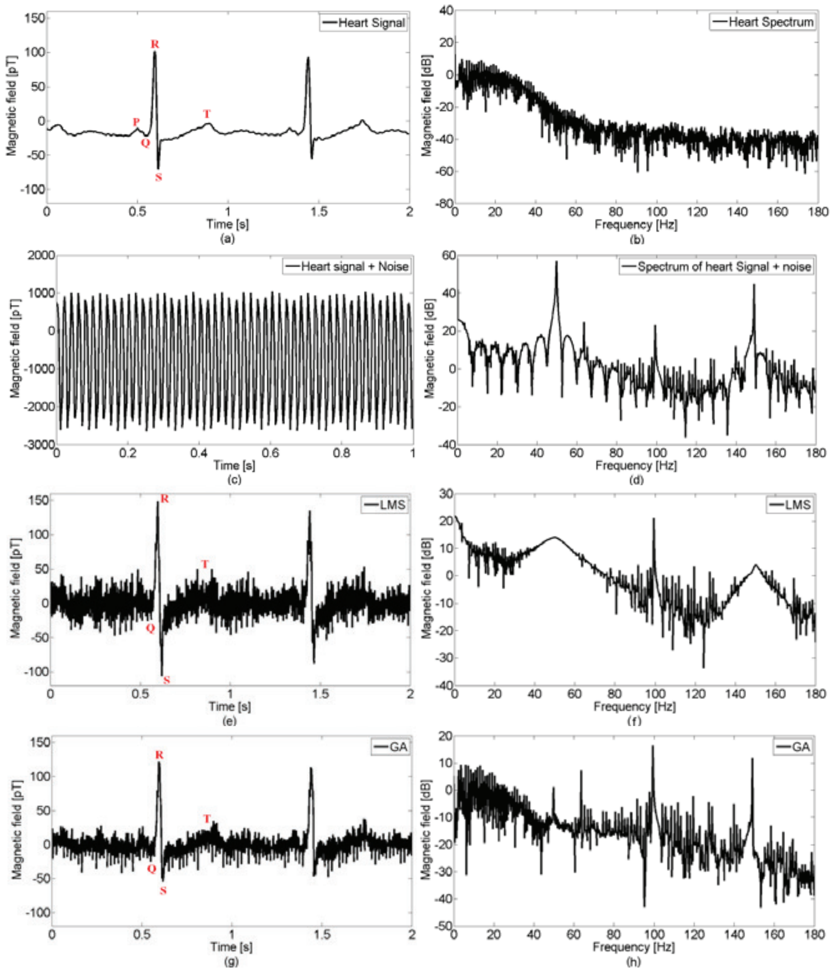

Fig. 2: (a) Measured heart signal showing the typical P wave, QRS complex and T wave, which correspond to atrial depolarization, ventricular depolarization and ventricular repolarization, respectively; (b) Spectrum of the heart signal; (c) Input signal of the noise canceller obtained by adding the heart signal to the environmental magnetic noise measured inside the laboratory; (d) Spectrum of the input signal of the noise canceller; (e) Heart signal recovered by LMS algorithm, calculated SNR improvement factor was 33 dB; (f) Spectrum of the heart signal recovered by the LMS algorithm; (g) Heart signal recovered by GA algorithm, calculated SNR improvement factor was 37.4 dB; (h) Spectrum of the heart signal recovered by the GA algorithm.

Figure 2 (e) and (g) show the heart magnetic signal recovered using the LMS and GA algorithms, respectively. It is obvious that for both recovered signals the QRS and T features are noticeable, whereas the heart magnetic signal recovered by the LMS algorithm is noisier, making the QRS complex and the T wave hardly detectable.

Figure 2 (f) and (h) show the spectra of the heart magnetic signals recovered by LMS and GA algorithms, respectively. It is important to notice that both algorithms are unable to completely cancel the noise at high frequencies; however, this is not crucial as most of the signal information lies in the low-frequency range.

CONCLUSION

The use of LMS and GA algorithms has been investigated for adaptive noise suppression and the recovering of heart signals in magnetically-unshielded environment. Measured heart signals and magnetic noise have been used to compare the performances of both LMS and GA algorithms in terms of SNR improvement and heart peaks reconstruction. Simulation results have shown that the GA algorithm attains better SNR improvement than the LMS algorithm. A measured heart signal has been recovered by the GA algorithm with a SNR improvement of 37.4 dB and the QRS complex and T wave have successfully been detected. The LMS algorithm has also recovered the input signal, however, with a lower SNR improvement of 33 dB and noisy QRS complex and T wave. The noise cancellation results shown in this paper are useful for signal processing applications where the signal to noise ratio is much below unity.

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