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A new method for removal of powerline interference in ECG and EEG recordings ☆

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ABSTRACT

Advanced medical diagnosing and research requires precise information which can be obtained from measured electrophysiological data, e.g., electroencephalogram (EEG) and electrocardiograph (ECG). However, they are often contaminated with noise and a variety of bioelectric signals called artefacts, e.g., electromyography (EMG). These noise and artefacts which need to be reduced make it difficult to distinguish normal from abnormal physiological activity. Electromagnetic contamination of recorded signals represents a major source of noise in electrophysiology and impairs the use of recordings for research. In this paper we present an effective method for cancelling 50 Hz (or 60 Hz) interference using a radial basis function (RBF) Wiener hybrid filter. One of the main points of this paper is the hybridization of the RBF filter and a Wiener filter to make full use of both merits. The effectiveness and validity of those filters are verified by applying them to ECG and EEG recordings. The results show that the proposed method is able to reduce powerline interference (PLI) from the noisy ECG and EEG signals more accurately and consistently in comparison to some of the state of-the-art methods and this method can be efficiently used with very low signal-to-noise ratios, while preserving original signal waveform.

1. Introduction

Noise reduction is a matter of considerable importance in biomedical signal processing applications, especially electroencephalogram (EEG) and electrocardiograms (ECGs) analysis [1,2]. Non-cortical biological artefacts are the principal source of contamination in EEG recordings and they are generated primarily by movements, cardiac pulse, and muscle activity, particularly that of the face (especially the jaw) and neck. EEG experimental design is generally constrained by the desire to minimise the effect of these artefacts.

One useful categorization of artefacts is based on their origin: physiological (e.g., muscle and baseline noise) or technical, such as environmental interference caused by 50 or 60 Hz power-supply lines, radiation from lights, and radio frequency emissions from nearby medical devices. This categorization is also applicable to other bioelectrical signals.

On the other hand, powerline interference (PLI) coupled to signal carrying cables is particularly troublesome in medical equipment such as ECGs and EEGs. Cables carrying ECG and EEG signals from the examination room to the monitoring

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equipment are susceptible to electromagnetic interference (EMI) of power frequency (50 Hz or 60 Hz) by ubiquitous supply lines and plugs so much so that sometimes the ECG and EEG recordings is totally masked by this type of noise. Filtering such PLI signal is a challenging problem given that the frequency of the time-varying powerline signal lies within the frequency range of the ECG and EEG signals [1,2].

As mentioned above, PLI is a significant source of noise during bio-potential measurements [1,2]. EMI degrades the signal quality and overwhelms tiny features that may be critical for clinical monitoring and diagnosis, and it can strongly distort biopotentials. Numerous biomedical signals, such as ECG and EEG, contain distinct features in the time-domain analysis. There are diverse techniques for minimizing the appearance of unwanted interference, such as interference rejection of pre-amplified electrodes by automated gain adaptation [3]; subtraction procedure (SP) [4]; a Kalman filter (KF) [5]; PLI reduction based on S-transform [6], noise filtering using wavelets [7,8] and empirical mode decomposition (EMD) [9]. Another well-known method for cancelling the 50/60-Hz interference is using a notch 50/60-Hz filter [10,11]. The notch filter (NF) has two main traits. On the one hand, is able to reject a 50/60-Hz narrow frequency and, on the other, can maintain the remaining spectrum without hardly any change. However, this solution is not robust under frequency variations of the interfering signal, which happens unavoidably within a low-quality environment [12]. Therefore, although this solution is easy to be implemented at low cost, it produces undesirable signal distortion and cannot eliminate completely the interference [12]. Another method that is potentially capable of reducing the 50/60-Hz ECG interference is an adaptive filter (AF) [13–15]. This system is based on an adaptive filter that has the capability of automatically adjusting its parameters to obtain the best performance under a variable interference [1,2].

Radial basis function (RBFs) neural networks as a kind of powerful kernel methods have been applied to many areas with success [16–19]. The theoretical analysis of RBF structures and algorithms includes the orthogonal least square algorithm, the approximation capability analysis [17,18,20], the design of RBF structure using fuzzy clustering method, the optimization of RBF structure using kernel orthonormalization method or combined supervised and unsupervised learning method, and the use of Fisher separability ratio for the selection of RBF centres. The RBF is selected because of its compact support [17,18,20]. Regarding Wiener filter, it has been implemented with different structures for noise suppression applications as MEG signals, acoustic signals, etc. [21].

In this paper, a new PLI reduction method based on a RBF–Wiener hybrid filter (RBFWF), is proposed. The proposed filter is realized with a least mean square error scheme using higher order statistics of a target signal and a powerline interference. The proposed RBF network has been developed like a hierarchically layered structure. It starts with a small number of RBFs and then adds new RBFs if the approximation error is larger than some predetermined threshold and there is no existing RBF that can efficiently represent the current input. Computer experiments have demonstrated that the developed algorithm can improve the PLI reduction over the systems compared. Furthermore the results have shown that this new method can maintain the original shape of the EEG and ECG signals in very low SNR conditions in which the brain or heart signal is mixed with the noise. Several important advantages have been obtained with this system. Firstly a low distortion of the signal has been caused, clinical information has been maintained, and finally this system could be applied to a wide range of biomedical signals. Experiments with real and synthesized recordings have been discussed, and the results have shown the validity of the proposed method.

The paper is organized as follows: Section 2 introduces the materials used in this study. Section 3, presents our proposed approach. The description of the experiments and the discussion of the results are given in Sections 4 and 5 respectively. Finally, the conclusions of this paper are summarized in Section 6.

2. Materials

In order to check the effectiveness of the proposed denoising algorithm, several experiments with synthesized and real recordings were performed. On the one hand, real ECG signals from Physionet [22], they were composed of the MIT–BIH Noise Stress Test database, PAF Prediction Challenge database, the MIT-BIH Normal Sinus Rhythm database, MIT-BIH Atrial Fibrillation database, MIT-BIH Arrhythmia database, St. Petersburg Institute of Cardiological Technics, MIT-BIH Arrhythmia Database, Long-Term ST Database, etc. And, on the other, real EEG signals (Table 1), they were obtained from Psychiatric and Neurophysiology departments in the hospital Virgen de la Luz in Cuenca (Spain). The electrodes were placed according to the International 10–20 System. EEG data were recorded at 250 Hz using Brain Vision with 32 channels. The vertical EOG (VEOG) signal was recorded from the right eye (2.5 cm below and above the eyeball); the horizontal EOG (HEOG) signal was recorded from the outer canthus. Reference was located on A2 (right earlobe). Besides, sleep studies were also included. All these

Table 1
Summary of the real EEG signals.

	Adults		Children
	(Average 31 year old)	(Average 22 year old)	(Average 14 year old)
Male	20	19	9
Female	22	20	10