Double Density Wavelet for EEG Signal Denoising

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Abstract—EEG signals usually were contaminated with unwanted artefacts that may hide some valuable information in the signals. In this paper, we implemented wavelet based image processing techniques known as 1-D Double Density and 1-D Double Density Complex for denoising EEG signals at various windows size. The performances of these methods were compared and evaluated by calculating the Root Mean Square Error (RMSE). The minimum RMSE was achieved at the threshold value of 20. The 1-D Double Density Complex was outperformed 1-D Double Density and was effective in EEG signals denoising.

Keywords—EEG, 1-D Double Density Wavelet, 1-D Double Density Complex Wavelet, Denoising

I. INTRODUCTION

The electric signals of human brain which known as electroencephalography (EEG) were used extensively in a clinical studies since its discovery in 1870’s. The EEG signals carry important information regarding brain function and can be used as a diagnosing tool of many diseases such as, epilepsy, sleep and mental disorders. However, this signal always suffers from variety of artefacts and noises that occur during EEG recording. Amongst them were muscle movements, baseline wander due to eye movement and 50/60 Hz powerline interference. Extensive works were carried out in the signal filtering or denoising fields in order to remove the unwanted artefacts from the original signal and at the same time preserved the important information in the original signal. A linear and nonlinear filter was proposed by some researchers to fulfill this task [1-5]. However, further works are still required to improve the filter performance.

Wavelet which was introduced to overcome the resolution limitation of spectral analysis of Fourier transform has an ability to denoise the corrupted image and signal. Over the past decade, the wavelet transform was expanded from the basic Discrete Wavelet Transform (DWT) to more complex types of DWT such as 1-Dimensional (1-D), 2-Dimensional (2-D), and Higher Dimensional of Double Density and Double Density Complex [6]. These expansive types of DWT were used largely in image denoising [6, 7] but this approach has not been implemented in the biological signals.

The aim for this work is to adopt the 1-D Double Density and 1-D Double Density Complex for denoising EEG signals and to evaluate the performance of both techniques at optimal threshold point for four windows size of 10s, 30s, 60s, and 300s.

II. METHODS

A. Data

EEG signals were recorded using a standard 10-20 system. The surface electrodes were placed on the scalp locations C3, C4 and O2 and were referenced to bridge the left and right mastoid. The sampling frequency was 256 Hz and the signals were recorded by using Bio-Logic System and Adults Sleepscan Vision Analysis (Bio-Logic Corp, USA). This overnight study was conducted at St. Lukes Hospital, Sydney, Australia. For this denoising experiment, the EEG signals of ten subjects were randomly selected from our database. The EEG signals were segmented to 10 s, 30 s, 60 s, and 300 s in order to find the appropriate window size that will give the optimum denoising results. The EEG data were processed and analysed using Matlab software (Mathworks, USA).

B. Denoising Techniques

The denoising techniques were implemented following the process proposed in [6].

(1) 1-D Double Density DWT (DD)

The DD was consisted of two stages of filter banks as shown in Fig. 1:

(i) Analysis

In the analysis filter banks, three filters were implemented and the original signals \( \hat{x}(n) \) were down-sampled by 2 in order to decompose the signals into three sub-bands. The low frequency sub-band, \( c(n) \) was produced by low pass filter \( h_0(-n) \), and the two high frequency sub-bands \( d_1(n) \), and \( d_2(n) \) were produced by high pass filters \( h_1(-n) \), and \( h_2(-n) \).

(ii) Synthesis

The synthesis filter banks were the inverse of analysis filter banks where the three sub-bands were up-sampled by 2, filtered by the high pass filter \( h_3(n) \) and the two low pass filters \( h_1(-n) \), and \( h_2(-n) \). The filtered signals were combined to form the output signal \( x(n) \).
(2) Double Density Complex DWT (DDC)

The input data \( \hat{x}(n) \), were processed by two parallel iterated filter banks \( h_i(n) \) and \( g_i(n) \) where \( i = 0, 1, 2 \). The real part of a complex wavelet transform was produced by the subband signals of the upper DWT and the imaginary part was produced by the lower DWT as in Fig. 2. The implementation process for DDC was shown as a flowchart in Fig. 3.

C. Performance Evaluation

The denoising performance of each wavelet technique was evaluated by calculating the Root Mean Square Error (RMSE) defined as

\[
RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} [x(n) - \hat{x}(n)]^2}
\]  

(2)

Where \( x(n) \) was the denoised signals and \( \hat{x}(n) \) was the original noisy signals. The Gaussian white noise of variance equal to 20 was added to the original signals \( \hat{x}(n) \). The effects of EEG windows size of both DD and DDC were also evaluated.

III. RESULTS

Both techniques were successfully removed the noisy signals but DDC was outperformed DD as spikes were more visible in the denoised EEG signals as seen in Fig. 4. Furthermore, RMSE of DDC was lowered than DD for threshold points between 5 and 20. The threshold point of 20 was observed to give a minimum RMSE regardless the size of window being used.

The performance of DD and DDC for window size of 60s was plotted in Fig. 5 to show the optimum value of threshold to be adopted in the denoising algorithm.

In our experiment to find the appropriate window size for denoising the EEG signals, it was observed a window size of 300 s yields the lowest RMSE at 7.331 for DDC as presented in Table 1.
IV. DISCUSSION

In this paper, 1-D Double Density (DD) and 1-D Double Density Complex (DDC) which were largely used in image processing methods were implemented on the EEG signals. It was observed that DD and DDC can be used for denoising EEG signals based on the performance evaluation. The RMSE values for these methods were comparable to the wavelet denoising technique reported in [8-9]. However, the performance of DDC was better slightly than DD. The RMSE value was slightly decreased when a longer window size was used. Therefore, these methods can be used in other biological signals like ECG where a window size of 300s was used for Heart Rate Variability analysis.

ACKNOWLEDGMENT

The authors gratefully acknowledge Mr. Gerard Holland from St. Luke’s Hospital (Sleep Centre) in Sydney (NSW, Australia), for providing continuous consulting, sleep monitoring and scoring input to our sleep research.

REFERENCES