Compression and Comparison of ECG Signals using DWT and DWPT

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Abstract

The work here attempts to incorporate the power of frequency domain tools like wavelets and wavelet packets for aiding data compression using runlength encoding. An attempt is made here to compare between the performance of wavelets and wavelet packets for data compression. The DWT is performed in one level with sym8, the coefficients are threshold by hard rule and encoding is done by zero run length. In case of DWPT the best tree is selected from level 8 decomposition based on maximum energy content in them and out of that sub bands, best bands are selected based on SVD.

Keywords: DWPT, DWT, ECG, Runlength Encoding

1. Introduction

Biomedical signals are non-stationary signals that are produced due the action and resting potentials associated with various parts of the body. They include ECG, EEG, EMG etc. Among these ECG is the most vital signal that are produced by the electrical potentials of the heart. ECG signals are usually sampled at the rate of 200-500 samples/s with a resolution of 8-12 bits. Hence compression is inevitable in order to reduce such large amount of data. The QRS complex or R-wave is the dominant feature of ECG and its accurate detection is vital in order to find out the arrhythmias related to heart. But the compression of ECG signal is a complex process as it has a time varying morphology, affected by noise from many sources and is subjected to physiological variations by the patient. Hence ECG compression is generally accomplished by detecting and preserving the QRS complex and by eliminating noise and redundant data.

Compression methods are of two types: Lossy and Lossless compression. In order to achieve the desired

Compression Ratio (CR), lossy compression is preferred as it simply eliminates the unnecessary data's. Lossless compression is based on the idea of breaking a data into smaller form for storage or transmission to distant places and reconstructing it exactly into the original signal. Generally lossy ECG algorithms fall in any of the two following categories:-

- Direct data compression methods, such as Amplitude Zone Time Epoch Coding (AZTEC), Coordinate Reduction Time Encoding system (CORTES), Differential Pulse Code Modulation (DPCM); which detects redundancies by analyzing the actual signal sample directly.
- Transformational methods that include Fourier Transform (FT), Discrete Cosine Transform (DCT), Wavelet Transform (WT); that represents the signal in both time and frequency domain at the same time.

This paper presents the latter method that includes Discrete Wavelet Transform (DWT) or Wavelet Packets to de-correlate ECG signal data for subsequent adaptive entropy coding. The ECG signal is first preprocessed by normalization, noise removal and zero padding which enhances the Compression Ratio (CR) and Percent Root Mean Square Difference (PRD). The compression process includes four stages: The noise reduction, the decomposition of the signal by Discrete Wavelet Transform (DWT) or Discrete Wavelet Packet Transform (DWPT), the thresholding of the wavelet Coefficients and the Run-Length Encoding (RLE).

The Wavelet transform and its variants decompose a signal into elementary coefficients that are localized both in time and frequency. The window size (scale) used in wavelet transform is chosen to be short at high frequencies in order to provide good time resolution and low at low frequencies in order to provide good frequency resolution. Thresholding of the wavelet coefficients are done depending on the desired energy packing efficiency, which enables to obtain the desired CR and PRD. Run-Length Encoding is a lossless data compression algorithm which reduces the physical size of a repeating data that can be decoded and reconstructed whenever necessary.

This paper is organized as follows:-section 2 gives a brief introduction of wavelet transform and Wavelet Packets, section 3 describes the methodology of the proposed technique, the results and analysis of the proposed technique is presented in section IV and section V provides the conclusions.

2. Basic Concepts

2.1 Discrete Wavelet Transform (DWT)

Discrete Wavelet Transform (DWT) allows the translation of time domain signals from time domain to frequency domain. The Multi Resolution Analysis (MRA) capabilities of DWT allows to separate frequency domain coefficients into lowpass or approximation coefficients and high pass or detail components. Figure 1 shows the decomposition of signals at level-1. The filters h_0 and g_0 shows the low pass and high pass filters respectively. And

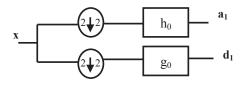


Figure 1. Level-1 decomposition of signals.

the coefficients a_1 represents the approximation coefficients and d_1 represents the detail coefficients. Usually the approximation coefficients carry the information and detail components mainly have noise in it.

The Figure 2 represents the reconstruction of the signals where h_1 and g_1 represents the reconstruction filters and \hat{x} shows the reconstructed output.

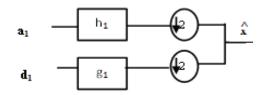


Figure 2. Reconstruction of signals.

For next level of decomposition the approximation coefficients are decomposed further and give next level of approximation and detail components. An n level decomposition gives 2^n basis in wavelet decomposition.

2.2 Discrete Wavelet Packet Transform (DWPT)

Wavelet Packet Transform can be considered as a generalization of wavelet transform where first level decomposition gives approximation and detail components same as in the case of wavelets. But further decomposition is done not only on the approximation coefficients but on the detail components also.

Figure 3 shows level-3 decomposition of DWPT. The dyadic representation gives a rich set of basis and there will be 2^n basis generated. Out of these best tree can be selected.

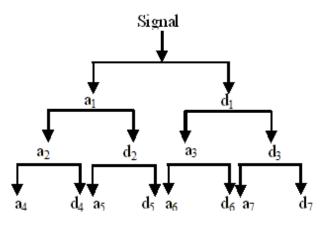


Figure 3. Level-3 decomposition of 1-D signal using wavelet packets.

2.3 Global Thresholding

The thresholding is applied on the transformed coefficients to reduce the noise. The thresholding can be either hard thresholding or soft thresholding. The thresholding applied here is global (universal) thresholding which is a soft thresholding technique. While thresholding, the wavelet coefficients that are greater than the threshold are shrunk towards zero and those that are less than the negative of threshold are increased by the threshold value.

Global thresholding is a global procedure and is defined as $T = \sigma \sqrt{2 \log M}$ where σ^2 is the noise variance and M number of samples in the image. The noise variance is calculated by taking the median value as

$$\sigma = \frac{\text{Median}(\lfloor d_i \rfloor)}{.6745}, d_i \text{ element of selected band.}$$

2.4 Runlength Encoding

It is a simple data compression technique which is used to compress a long sequence of digital data to a shorter sequence. It is done by representing a selected value that is repeated many times, according to the number of times of repetition. The repeating value is called a *run*, which is encoded into two bits. The first bit which is called as bit value, represents the value of the data, whereas the second bit which is called as run count represents the number of times it is repeated. An example of this algorithm is illustrated on Figure 4.

In this example, the selected value to do the encoding process is zero. So when each time a zero appears in the input data, it is represented as a two bit code called an RLE packet. Here the number of "0" s are counted and represented as "06" and "04", where '0' is the run value and '6' and '4' are the run count. Thus, after run-length encoding, the 15 bit data is compressed into an 8 bit data. Hence the compression ratio, which is the relation between the length of input data and the output data, is about 2:1. By decoding this output data, one can reconstruct the original signal without any loss.

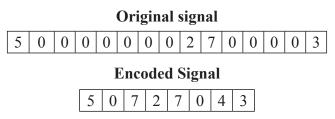


Figure 4. Run length encoding process.

2.5 Performance Measures

2.5.1 Compression Ratio (CR)

Compression ratio is a measure to evaluate the ability of the algorithm to compress or reduce the size of the original signal. Compression ratio is defined as the ratio of bit rate of original signal to the bit rate of reconstructed signal.

$$CR = \frac{b_{original}}{b_{reconstructed}} \tag{1}$$

boriginal: Bit rate of the original signal. breconstructed: Bit rate of the reconstructed signal.

2.5.2 Percent of Root Mean Square Difference (PRD)

Percentage Root Mean Square Difference (PRD) is used for evaluating quality of ECG signal reconstruction. It is the ratio of the difference between the original and the reconstructed signal to that of the original signal. It can determine the efficiency of a compression algorithm. PRD is defined as follows:

$$PRD = \frac{\sum_{i=1}^{n} (x_i - x_r)^2}{\sum_{i=1}^{n} x_i^2}$$
(2)

 X_i is the ith original data and X_r is the reconstructed version of X_i .

3. Methodology

For ECG signal compression runlength encoding is adopted. The encoding is carried out on transformed signals. For transforming both wavelets and wavelet packets

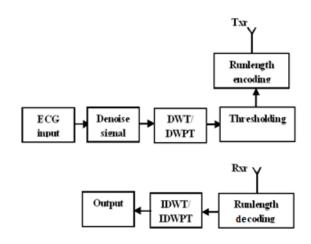


Figure 5. Block diagram of compression of ECG signals.

are tried. The general block diagram of the process is given in Figure 5. It shows that the acquired input signal is denoised first, since the ECG signals are prone to noises during its acquisition, transmission and reception. Then DWT is applied to get the frequency domain coefficients. The coefficients are thresholded before applying run length encoding scheme. These compressed signals can be transmitted. At the receiving end the compressed coefficients are decoded and the signal is reconstructed using IDWT. The same procedure is applied with discrete wavelet packet coefficients also.

The algorithm representation of the same is given in steps below:

- Select an ECG signal from MIT-BIH database.
- Normalize and denoise the signal by applying global thresholding.
- Apply DWT/DWPT
- if DWT,
- Obtain wavelet coefficientsby applying level-3 decomposition.
- Depending on threshold value, select the coefficients for encoding.
- else if DWPT,
- Obtain the wavelet packet coefficients at level-3 decomposition.
- Select the best bands depending on the entropy value of the bands.
- Encode the ECG signals using runlength encoding method.
- Transmit the ECG signal to the destination.
- Receive the signal.
- Decode using runlength decoding technique.
- Reconstruct the signal using IDWT/IDWPT.
- Evaluate the performance using CR & PRD parameters.

4. Results and Analysis

The experimental ECG signal records are selected from the MIT-BIH arrhythmia database. All ECG signals used are sampled at 360Hz frequency. The signals are normalized and denoised first. The wavelet transform is performed on these signals for transforming the signals into frequency domain before performing compression. The ECG signals under consideration are compressed using Runlength Encoding (RLE) method. The compressed signals can be transmitted. At the receiving end the compressed signals are decompressed and they are reconstructed by performing inverse wavelet transform. Alternatively, the coefficients to be compressed are generated through wavelet packet transform instead of wavelet transforms. The level-3 decomposition is performed for getting both DWT and DWPT coefficients.

The signals can be transformed to frequency domain using wavelet transform and its variants. The filters selected for wavelength decomposition are Daubaches wavelets and symlets. Db filters have similarity in shape with QRS complex of ECG signals. The performance evaluation is done with CR and PRD ratios. The CR and PRD values of reconstructed signals against original signals which have coefficients generated through DWT are tabulated in Table 1 below.

Table 1.	Performance parameters of different wavelets
at level-3	

Type of Filter	Level 3		
	PRD	CR	
Db2	2.99	50.2	
Db3	1.05	50.2	
Db4	0.2309	50.2	
Db8	0.0684	50.2	
Sym2	2.99	50.2	
Sym3	1.05	50.2	
Sym4	0.1871	50.2	
Sym8	0.0529	50.2	

Table 2. Shows the CR and PRD values of reconstructed ECG signals whose frequency domain coefficients are generated through DWPT.

Table 2.Performance parameters of different waveletspackets at level-3

Type of Filter	Level 3	
	PRD	CR
Db2	0.0039	12.5
Db3	0.006	12.5
Db4	0.011	37.75
Db8	0.017	37.75
Sym2	0.0039	12.5
Sym3	0.006	12.5
Sym4	0.0091	25.2
Sym8	0.0104	25.2

A graphical representation of original and reconstructed signals and the error between them are shown in Figure 6 and Figure 7. It shows reduced error in the case of coefficients generated through DWPT as compared to the coefficients generated through DWT.

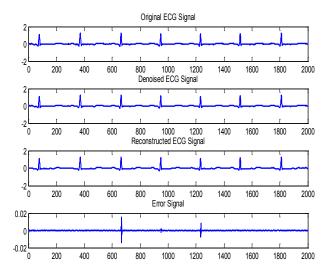


Figure 6. Graphical representation of error in compressed ECG signals with DWT.

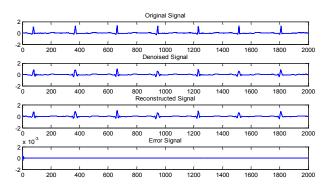


Figure 7. Graphical representation of error in compressed ECG signals with DWPT.

5. Conclusion

The paper describes two algorithms for compression using wavelets and wavelet packets with runlength encoding. The level-3 decomposition is applied for both wavelets and wavelet packets. The performance analysis shows that compression of coefficients generated with wavelet packets give better results than compression of coefficients generated with wavelets. The performance analysis is done in terms of CR ratio and PRD parameters. The error graph of DWPT outperformed DWT.

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