ECG Data Compression Using Wavelets

AV Chagas, EAB Da Silva[1], J Nadal

Biomedical Engineering Program, [1]Electrical Engineering Program, COPPE, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

Abstract

This work aims to apply the discrete biorthogonal wavelet transform and adaptive arithmetic encoding (AAE) for ECG data compression. Using the 9-7 linear phase biorthogonal wavelet and symmetric extension at the signal boundaries, the number of subband samples required for synthesis becomes the same as the ones of the original data. The encoding EZW algorithm was used to explore the similarities between subbands, and AAE to represent the generated symbols with a rate close to its entropy. Such method was applied to MIT-BIH Arrhythmia Database (24 Hs, 2 channels of data sampled with at 360 Hz with 11 bits), for different compression ratios (CR). Fixing CR to 12:1, the data shape is preserved. The obtained PRD, 3.58±1.56% (mean±standard deviation), indicates the suitability of the method.

1. Introduction

Although digital storage media are not expensive and computational power has exponentially increased in last years, ECG data compression is still object of investigation. It is important for applications such as digital storage of ambulatorial data, due to the compromise between memory capability and power consumption [1], and telemedicine, where data transmission is required through telephone lines or telecommunication networks.

Various powerful methods for signal and image compression are being proposed in recent literature, either using direct data compression and orthogonal transforms like Discrete Cosine Transform (JPEG) [2] and Discrete Wavelet Transform (DWT) [3-5]. DWT is particularly suitable for ECG and other signals for preserving both time and frequency resolution.

This paper aims at applying discrete biorthogonal wavelet transform and adaptive arithmetic encoding (AAE) for ECG data compression.

2. Biorthogonal wavelets

The DWT constitutes a multiple resolution decomposition of signals, where original data is represented by a weighted sum of basis functions (daughter wavelets), which are dilated and translated versions of a prototype function called mother wavelet [3]. The coefficient of each wavelet function corresponds to the projection of the signal on this function, and can be obtained by decomposing the signal using a filter bank (Figure 1). The coefficients in each scale are calculated using low-pass and high-pass filters, its coefficients being respectively denominated j-level of approximation and detail subband.

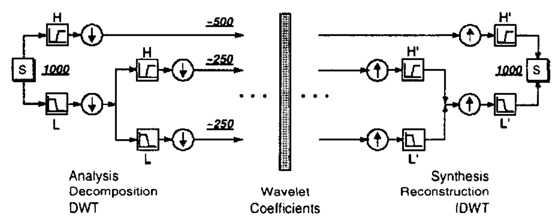

Figure 1. Discrete wavelet analysis and synthesis using a filter-bank

A wide variety of functions can be chosen as the mother wavelets. The main advantage of using biorthogonal wavelets is the use of dual scaling functions and wavelets for synthesis and analysis. It allows perfect reconstruction of data while using filter banks with linear phase. One of the main advantages of using linear-phase wavelets is that it allows the use of symmetric extension of data, which avoids border effects at the beginning and end of the data segments. Several such functions have been tested, but, due to space limitations, in this paper only the results corresponding to the 9-7 biorthogonal wavelet [4] (Figure 2) are shown, since it has already been applied to ECG compression [1,3,5].

3. EZW compression

When image or signals are coded with high compression rates (low bit rates), the coding of the coefficient positions consumes too many bits. This is specially important for bit rates lower or equal to 1 bit/sample, when the quantity of null (or non-significant) coefficients becomes high. In this case, a significant fraction of bits of generated code are used to represent

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non-significant information. The Embedded Zerotree Wavelet (EZW) coder [4,6] aims at reducing the cost of coding the positions of coefficients that are different of zero, and it obtains the best reconstructed signal quality for a given bit rate under the constraint that the encoding is embedded [3].

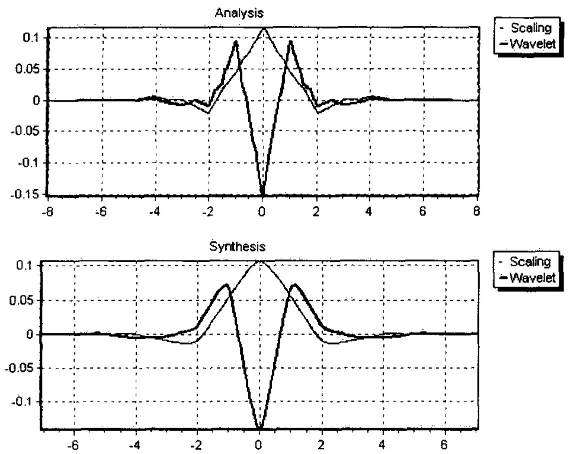

Figure 2. The 9-7 Biorthogonal wavelet

It uses the experimental finding that the amplitudes of wavelet coefficients decay from higher to lower scales or levels. Thus, a coefficient is considered non-significant when it is lower than a pre-defined threshold, and when it is insignificant for a given scale, it is probably non-significant for all the lower scale and the same threshold. Thus, it becomes possible to represent data segments in a hierarchical order, from coarse approximation to details. When signals are represent by subbands, the low-pass (father) coefficient at a given level can be related to the ones (sons or descendants) obtained for the successive levels. A zerotree is obtained when a father coefficient and all its descendents are not significant for a given threshold. In this case, such coefficient is properly encoded as a root of a zerotree, which means that its descendents will not be considered for compression and reconstruction. EZW is performed by an iterative sequence of steps, by evaluating the coefficients in a progressive hierarchical order. Thus, the compression can be stopped when a target bit rate is reached. This allows a precise control of both the percent root-mean-square difference (PRD) and root-mean-square error (Erms), for each selected compression ratio (CR).

Optimal bit allocation is obtained when all subbands present the same mean distortion [7]. As it is not true for biorthogonal wavelets, it becomes necessary to use a correcting factor for each subband. In the present case, the proper standard deviation of the coefficient is used as coding gain (or weight) for each subband. During synthesis, each coefficient must be divided by the same factor, previously to the inverse transformation [7].

4. Application to ECG data

The algorithms were developed and optimized using the short ECG segments of the ECG Compression Database, and evaluated with the 30 minutes, two channels, ECG segments from the MIT-BIH Arrhythmia Database (MITDB), which were digitized at rate 360 samples/s and 11 bits resolution [8].

For quantitatively assessing the quality of compression, it was used the well accept PRD given by:

$$PRD = \sqrt{\frac{\sum_i [x(i) - \hat{x}(i)]^2}{\sum_i [x(i) - K]^2}} \quad (1)$$

where x and $\hat{x}$ represent, respectively, original and reconstructed data, and K is an estimate of mean noise, usually defined as the mean value of the original signal. In the case of MITDB, K was set as 1024 - the previously defined level for ECG baseline into database.

Signal quality for medical use was also evaluated, by visual inspection.

5. Results

The database was compressed for progressively higher values of CR, from 4 to 20, being calculated the PRD and its mean values and standard deviations for each data channel and the complete set (Figure 3).

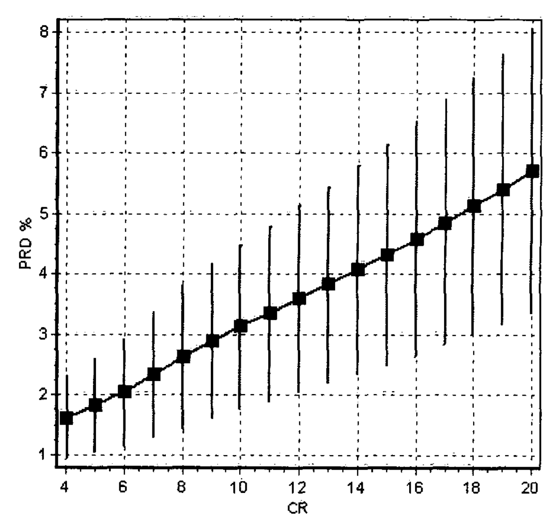

Figure 3. Mean values and standard deviation of PRD(%) obtained for different compression ratios

By inspection, it was observed that the quality of signal is maintained for CR up to 12 (Figure 4), when the respective parameters PRD and Erms present the values shown in Table 1.

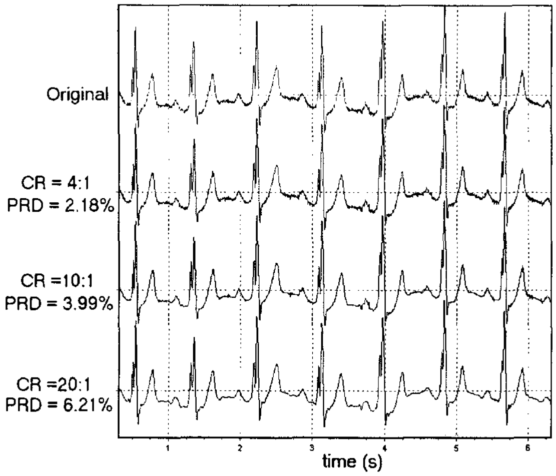

Figure 4. Original ECG segment and reconstructions obtained after different compression ratios

Table 1. Results of the compressor for the complete database (Compression Ratio 12:1)

	Channel 0		Channel 1		Total	
	PRD (%)	Erms (μV)	PRD (%)	Erms (μV)	PRD (%)	Erms (μV)
Mean	3.38	15.4	4.55	14.3	3.58	14.90
SD	1.48	4.20	2.77	4.30	1.56	3.95

6. Discussion

It was developed a method based on discrete biorthogonal wavelet transforms and adaptive arithmetic encoding using EZW for ECG data compression. To permit unbiased comparison with literature, it was selected the 9-7 biorthogonal wavelet, previously reported [1,3,5], which was applied to same signal from the MIT-BIH Arrhythmia Database. As in the present work, Hilton [3] used the EZW compressor, while Lu *et al.* [5] used the algorithm SPIHT (Set Partitioning in Hierarchical Trees) and Djorhan *et al.* [1] used the Hufman code. The comparative results (Table 3) suggest that the present results are similar to the ones from [5] and significantly superior to the others. A possible reason for these differences is the value of K. The works with better results adopted $K = 1024$, and the others do not indicated the used value, that may be different.

When results are compared for a large set of signals (MITDB patients 100, 101, 102, 103, 107, 109, 111, 115, 117, 118 and 119), the present method shows a performance better than [5] for all CR above 5:1. Partially, it should be explained by the time extension of the signals used for evaluation. The present results refer to the complete data segments (30.93 minutes) and [4] used only the initial 10 minutes from each patient. Additionally, the increased performance is due to the coding gain factor [6] that allows an optimal allocation of bits.

Table 2. Comparison of results for patient 117 (MITDB)

Algorithm	PRD (%)
Djohan *et al.* [1]	3.9
Hilton [3]	2.6
Lu *et al.* [5]	1.18
Present work	1.22

Table 3. Comparison of results for 11 ECG signals

PRD	CR						
	4:1	5:1	8:1	10:1	12:1	16:1	20:1
Lu *et al.* [5]	1.19	1.56	2.46	2.96	3.57	4.85	6.49
Present work	1.30	1.46	2.01	2.36	2.69	3.49	4.46

The pointed out quantitative results, as well as the maintenance of the overall characteristics off the ECG data segments form CR values up to 12, including the cases with worst values of PRD, indicates de suitability of this method for ECG compression. The compression method presented, which was successfully applied to image compression in previous works [6,8], is independent of the domain-specific knowledge, being potentially applicable for a wide variety of one-dimensional signals.

Acknowledgements

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Address for correspondence

Jurandir Nadal
Biomedical Engineering Program - COPPE
Federal University of Rio de Janeiro
P.O. Box 68510
21945-970 - Rio de Janeiro - RJ
BRAZIL
jn@peb.ufrj.br