MULTI-RESOLUTION ANALYSIS AND LOSSLESS ENCODERS IN THE COMPRESSION OF ELECTROCARDIOGRAPHIC SIGNALS

ANÁLISIS MULTI-RESOLUCIÓN Y CODIFICACIÓN SIN PÉRDIDA DE INFORMACIÓN EN LA COMPRESIÓN DE SEÑALES ELECTROCARDIOGRÁFICAS

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Recibido: octubre 2009
Aprobado: febrero 2010

Abstract

Many algorithms have been developed in the compression on biomedical signals. One of the most commonly compressed signals correspond to the electrocardiographic signal because is frequently measurement in environment hospitals. In this paper, we present the comparison of two methods based on multi-resolution analysis and lossless encoders, specifically Discrete Wavelet Transform and Huffman-Run length. In the performance of the algorithms, we analyzed two parameters: the compression ratio (CR) and the percentage of roots mean square (PRD). Our algorithms presented a CR of 8:1 to a PRD of 0,5%, which are good results in clinical applications, because the main characteristics in time and frequency are preserved.

Key words

DWT, encoders, compression rate, percentage root mean square difference.

Resumen

Muchos algoritmos se han desarrollado en la compresión de señales biomédicas. Una de las señales que con mayor frecuencia se comprime corresponde a la electrocardiográfica, ya que frecuentemente se registra en ambientes hospitalarios. En este documento se comparan dos métodos basados en el análisis multirresolución y codificadores sin pérdida de información, específicamente la Transformada Wavelet Discreta y los codificadores Huffman y Run-lenght. Se analiza el desempeño del algoritmo teniendo en cuenta dos parámetros: la relación de compresión (CR) y el porcentaje de error medio cuadrático (PRD). Los algoritmos presentaron un CR de 8:1 para un PRD de 0,5%, los cuales son buenos resultados en aplicaciones clínicas, ya que preservan las características en tiempo y frecuencia de la señal.

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Palabras clave
Transformada Wavelet Discreta, codificadores, relación de compresión, porcentaje de error medio cuadrático.

1. INTRODUCTION

In digital systems, the quantity of the information transmitted must to be the most compact possible, because the redundancy in the information can modify the performance of the system. The compression algorithms have the task of finding the redundancy in the information and eliminate it.

In preliminary work [1] a model for the biomedical signal compression based on Huffman method with a single source tree was presented. Additionally [2], established the relation between CR and the number of bits of quantization, of such form that for the case of 10 bits, with one dictionary, the value of CR was 7,92 with PRD of 3,3%. Other authors [3], have made the comparison between LZW, Huffman and run length encoding method and established better results in Huffman [4]. Proposed an algorithm of ECG data compression by adaptive average beat subtraction of DWT coefficients and Huffman coding; its CR was 4 to 15 and PRD was 0,05% to 1,5%.

We proposed a modification of run-length and Huffman algorithms with a low computational cost (low time, low quantity of operations). When the compression system uses run-length encoder, the coefficients are represented using linear quantization, with few levels; the CR is directly related to the quantity of consecutive zeros in the wavelet decomposition and the wavelet family, and also related to levels of decomposition and their thresholds. In the case of Huffman encoding we apply linear quantization, level by level, by using thirty-two ranges in each level and one hundred twenty eight ranges in total; we calculate the Huffman tree for each level and we assigned the code for each range. The CR was calculated by the relation of the number of bits of the original signal to the number of bits of the encoded signal and the PRD was calculated in the receptor with the reconstructed signal. In this paper, we found the best results with a Huffman scheme, which has a CR of 8,0 and a PRD of 0,5%.

2. BACKGROUND

2.1 WAVELET TRANSFORM

The Discrete Wavelet Transform (DWT) is classified as a multi-resolution analysis method because at each level we can determine the features for a specific bandwidth; where the bandwidth is directly related to the level of decomposition. The coefficients of upper frequencies are denominated “detail” and the lower frequencies “coarse” [5].

2.2 RUN LENGTH ENCODING ALGORITHMS

This method is used when a character (commonly zero) is repeated many times in a row, then the data in the original stream is replaced by the number and its repetitions. The length of the new data decreases when the quantity of zeros increases.

2.3 HUFFMAN ENCODING ALGORITHMS

Huffman encoding uses the frequency of repetition of the data for the length determination of the code. When the data have highest frequency this code is the shorter and when the data have the smallest frequency the code is the longest.

2.4 COMPRESSION RATIO (CR)

It is defined by the equation [6]:

$$CR = \frac{bits\_original}{bits\_encoded} \quad (1)$$

Bits_original: is the total of bits in a second which are transmitted of the ECG signal. For this, the system uses an A/D of n bits. Bits_encoded: is the total of bits in a second of the encoded signal.

2.5 PERCENTAGE OF RELATION OF DISTORTION (PRD)

The equation is expressed as:

$$PRD = \frac{\sqrt{\sum_{i=1}^{L}\left(x_i - \widetilde{x}_i\right)^2}}{\sqrt{\sum_{i=1}^{L}\left(x_i\right)^2}} \quad (2)$$

3. SOFTWARE IMPLEMENTATION

The MIT ECG Database was used in the validation of the algorithm, specifically the 100 record. Matlab 2009b version was selected and used the toolbox wavelet and signal processing. The algorithm for compression of biomedical signal included two steps: the transmitter and the receiver. We developed the following blocks in the transmitter: wavelet decomposition (DWT), threshold application and Huffman and run length coding; while in the receiver: decoding the frame data and the reconstruction (IDWT).

3.1 WAVELET TRANSFORM

We use Daubichies, Symlets and BiorSplines family (db6, sym6, bior5.5) with three levels of decomposition. The total of levels was selected according to the spectral characteristics of the ECG signal and the results of previous works.

3.2 THRESHOLD

We explore different levels and thresholds. For example, we used two methods for estimate the threshold, and soft and hard application, were considered. The threshold was estimated level by level, by using the calculus starting from the length of the signal and the amplitude of the coefficients.

3.3 CODING

The run length and Huffman encoders were used in its digital representation. We compare the performance of each encoder through the calculus of PRD and CR.

Huffman: we generated four trees Huffman by applying thirty-two ranges in each group of coefficients (d1, d2, d3, c3). The architecture used is static, which means signals are digitized with the same codes generated at the beginning. We calculated four increments (Δ), the equation for the last level for coarse coefficients was:

$$\Delta = \frac{\max(c_3) - \min(c_3)}{tr - 1} \quad (3)$$

tr corresponds to the total of ranges, max(c3) is the maximum of the amplitude of the last coarse coefficients and min(c3) is the minimum of the amplitude of them. Frequency corresponds to the total of data in each range. In the case of coarse coefficients (c3), 16 ranges have frequencies different from zero.

The Huffman code assigned to the ranges with frequency zero correspond to the longest code. The structure of the algorithm uses conditional if to establish the range in which the data are found, "data" is related to the Huffman code of each range, "total" is the digital data and c3 is the coarse coefficients. Depending on the range, the data are digitized by taking the minimum value of its range and the Huffman code is assigned.

The encode block diagram is shown below:

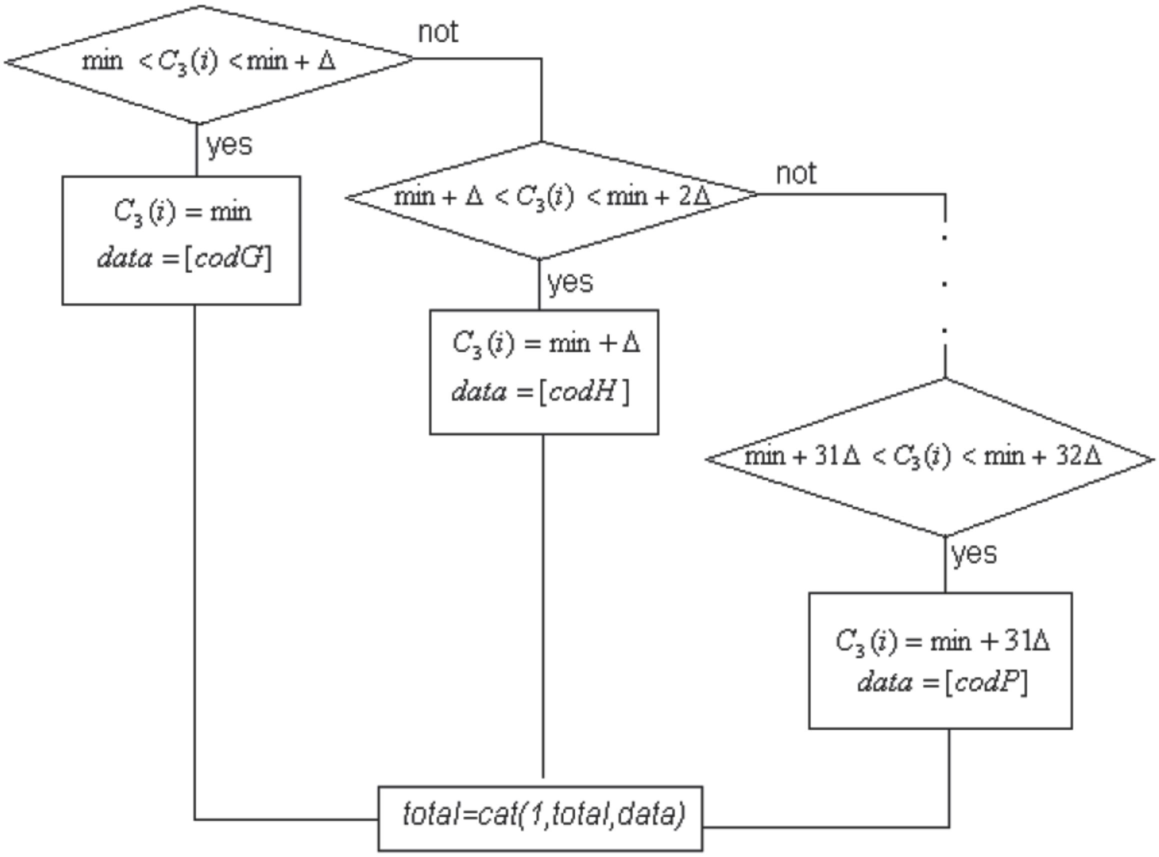

Figure 1. Block diagram (partial) of the Huffman algorithm.

Run length: The vector D is composed of detail coefficients (d3, d2, d1) and coarse coefficients (c3) and its length is saved into the constant appropriate. We used the vector D to calculate the run length code. The consecutives (zeros) were counted and its value was assigned to the total vector. The algorithm developed is presented in Figure 2.

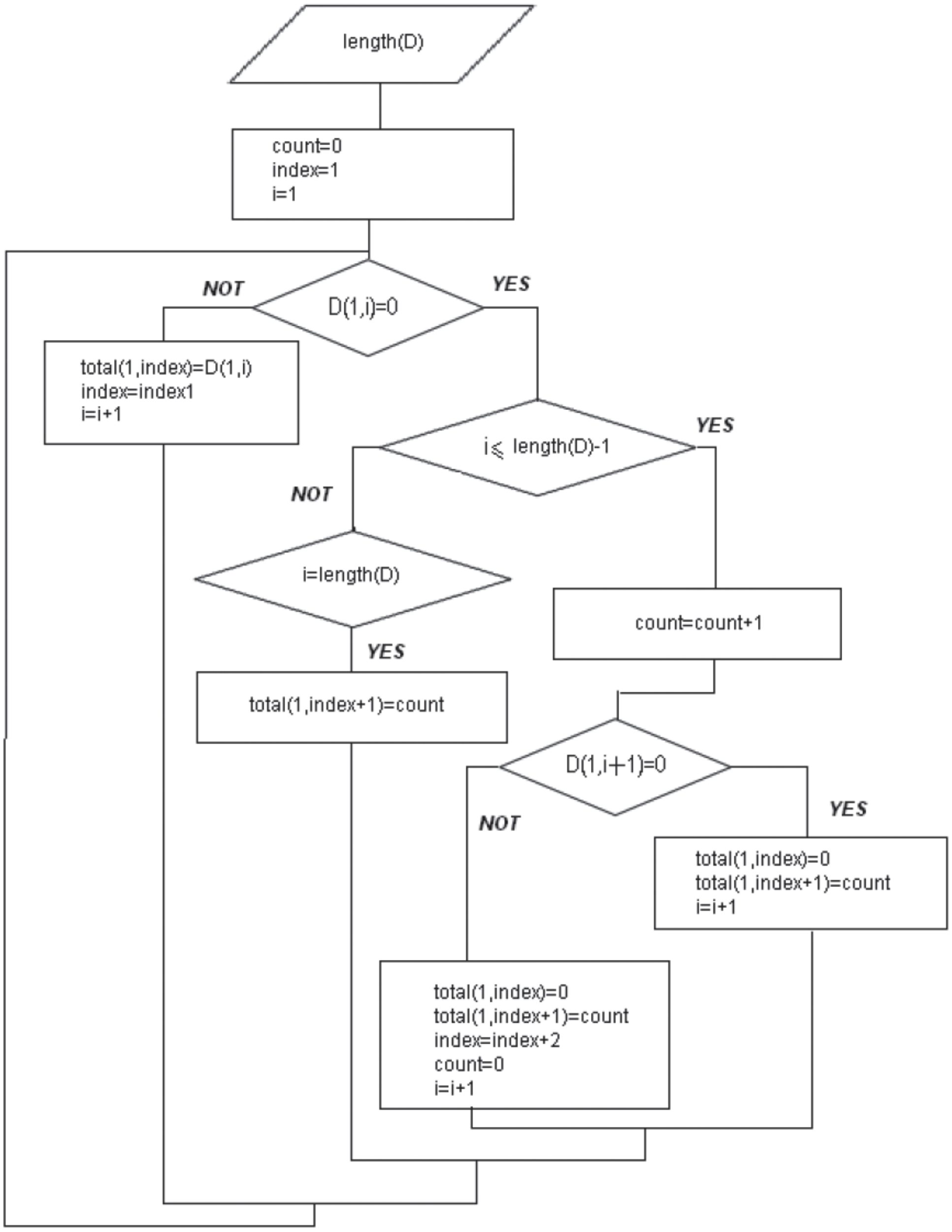

Figure 2. Block diagram (partial) of the run length algorithm.

4. RESULTS

The following results were found in the project.

4.2 SIGNAL COMPRESSED: HUFFMAN & RUN LENGTH ENCODERS

After the decomposition process was done, the codes were applying in the wavelet coefficients. In the case of run length, the codes were digitized by A/D converter of 7 bits.

Figure 3 presents two seconds of the signal with the following parameters used:

* Wavelet transform: three levels and sym6 (left), db6 (right)

* Threshold: sqtwolog + soft + mln

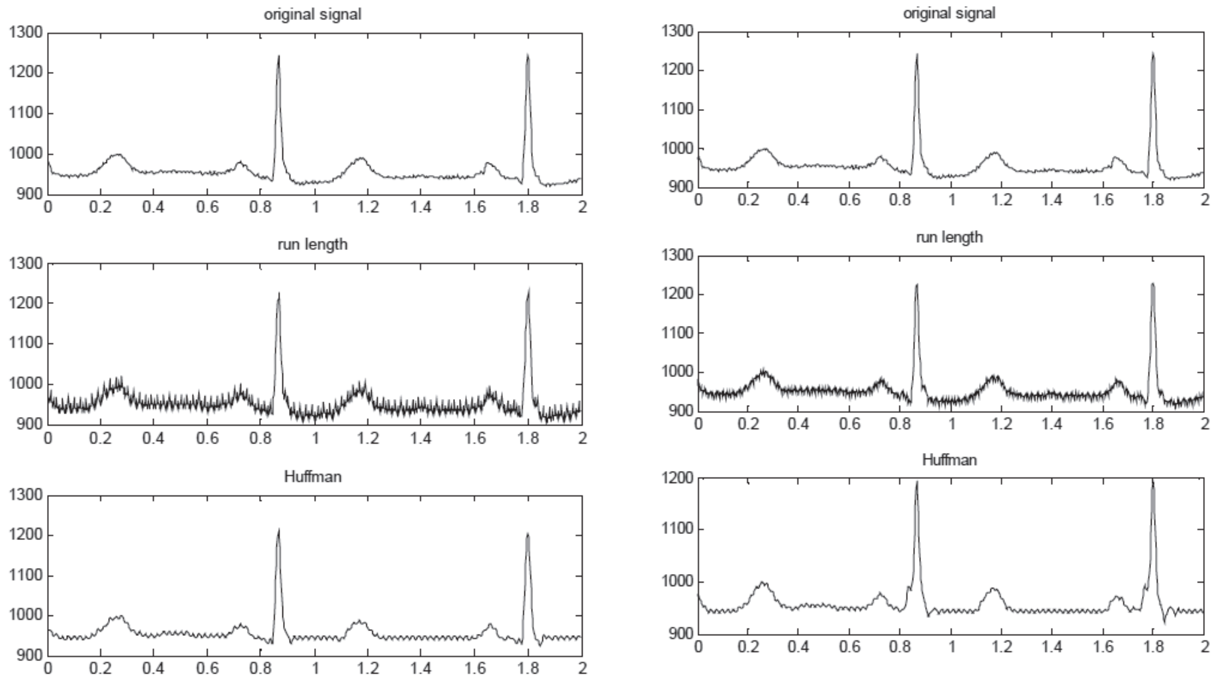

Figure 3. Signal compressed: rung length & Huffman, record 101.

The quality of compressed signal is better in Huffman case, which preserves the clinical ECG characteristics: times, amplitudes and behavior.

4.3 CR & PRD

The algorithm developed in Matlab provides the following results in the two coding methods used (Table 1). When lineal quantization is applied, the PRD is 0,0928% and the CR is 1.0.

Method	CR			PRD%		
	db6	sym6	bior5.5	db6	sym6	bior5.5
Huffman	4,0223	4,0843	4,1076	0,4765	0,4541	0,5276
Run length	5,2174	5,4962	5,6693	2,0869	0,7585	1,7105

Table 1. Mathematical results.

Because PRD of less than 1% is a requirement in clinical applications then bior5.5 and db6 bases are discarded in the encoding with run length.

When the number of bits in the quantization increases, we obtained:

Method	**CR**			**PRD%**		
	8	**9**	**10**	**8**	**9**	**10**
Huffman	4,6677	5,2512	5,8347	0,4541	0,4541	0,4541
Run length	5,4962	5,4962	5,4962	0,5984	0,5735	0,3414

Table 2. Results with different number of bits.
Wavelet family: sym6.

5. CONCLUSIONS

When the PRD is major of 1%, the initial and final time in each segment of the ECG signal can be modified, for this reason, a low PRD is necessary in clinical application, which is important to conserve the characteristics in time and frequency.

According to the results presented in Table 1, the method that yields better compression for the 100 record of the ECG signal is the Huffman encoder, which retained the clinical characteristics of the signal (PRD1%). In connection with the base, best results were obtained with sym6 both for the encoding Huffman and run length.

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