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ECG Compression using Wavelet Packet, Cosine Packet and Wave Atom Transforms.

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Abstract

This paper presents and analyzes Wavelet Packet, Cosine Packet and Wave Atom Transforms based electrocardiogram (ECG) compression. The ECG signal is first transformed using these transforms. The transformed coefficients are thresholded in order to match the predefined user specified percentage root mean square difference (PRD) within the tolerance. The non-zero thresholded coefficients are then quantized and encoded by arithmetic coding. The results are presented on different ECG signals of varying characteristic. The results show that Wavelet Packet Transform gives better performance at high PRD where as at low PRD, Wave Atom Transform performs better.

Keywords: ECG Signal, Compression, Wavelet Packet, Cosine Packet and Wave Atom Transform.

Introduction

The importance of ECG compression is well justified from the necessity of reducing the quantity of information an ECG recording session produces [1]. Biological signal, especially ECG has an important role in diagnosis of heart diseases [2].As more and more hospitals around the world are implanting the use of the electronic patient record (EPR), reducing storage requirements for clinical examinations (like ECG) is essential to include the results of these examinations with in the EPR without the saturation of the storage system [1]. On the other hand, reduction of the transmission rate in real-time telecardiology projects is usually required since the transmission bandwidth is always a valuable resource in communication networks. The key concept in both cases is to preserve the diagnostic quality of the original signal. In this way, the achievement of a high compression factor presents a constraint: not compromising the quality of the signal for diagnoses purposes [1].

The main goal of any compression technique is to achieve maximum data reduction while preserving the significant signal morphology features upon reconstruction [3]. Data compression methods can be classified into two main families: lossless and lossy methods. Methods from the lossless family can obtain an exact reconstruction of the original signal, but they do not achieve low data rates [4]. In contrast, lossy methods do not obtain an exact reconstruction, but higher compression ratios can be obtained [1]. The commonly used ECG compression techniques are lossy in nature. These mainly fall into two categories [4] [5]: (i) direct methods, in which actual signal samples are analyzed (time domain) [3]. Direct compression such as Amplitude-Zone-Time Epoch Coding (AZTEC) method, the coordinate reduction time coding system (CORTES), turning point (TP) technique, Scan-Along Polygonal Approximation (SAPA), peak-picking, cycle-to-cycle, differential pulse code modulation (DPCM) and the long-term prediction (LTP) [6][7] and (ii) Transformational methods, in which first apply a transform to the signal and do spectral and energy distribution analysis of signals [3]. Some of the transformations used in transformational compression methods are Fourier transform, Walsh Transform, Karhunen-Loeve Transform (KLT), discrete cosine transform (DCT) [8]-[10] and Wavelet Transform (WT) [11][12]. In most cases, direct methods are superior than transform based methods with respect to system simplicity and error. However, transform methods usually achieve higher compression ratio [4] [13].

Recently, Velasco *et al.* [2] designed a block based ECG compressor using wavelet packet (WP). WP based techniques are efficient than discrete wavelet transform (DWT) based method [15] for ECG compression [2]. Among the methods mentioned above, wavelet transformation is an efficient tool in signal processing aimed at compressing ECG signals [13]. Recently Laurent *et al.* [18] presented the Wave Atom Transform for image compression to the knowledge of authors this technique has not been yet explored for ECG compression. This paper applies the Wave Atom Transform and the results are compared with that of Wavelet Packet Transforms and Cosine Packet Transforms based ECG compression.

The main novelties of the research work presented in this paper are: (i) use of Wave Atom Transform for ECG compression, (ii) quality controlled ECG compression and (iii) comparison of Wavelet Packet Transform (WPT), Cosine Packet Transform (CPT), Wave Atom Transform (WAT). The paper is organized as follows: Section II describes different transforms, performance metrics are explained in section III. Section IV presents the methodology. Finally, results and concluding remarks are given in section V & VI respectively.

Transforms

Transforms are used to obtain a suitable signal representation for efficient source coding.

A. Wavelet Packet Transform (WPT)
WPT of a signal of length N performs a dyadic division of the frequency axis, using a fast filter bank algorithm that requires $O(2KN\log_2 N)$ operations, where K is the filter bank length. The resulting representation is an array of $(J+1)$ rows and N columns, where J is the number of dyadic decompositions [19].

B. Cosine Packet Transform (CPT)
Also known as dyadic Local Cosine Transform, CPT of a signal of length N performs a dyadic division of the time axis, applying to each time bin a discrete cosine transforms. Although the decomposition does not have to be dyadic, it has the advantage of creating a tree structure like in the wavelet packet case, allowing the implementation of fast bestbasis search algorithms [20]. The decomposition complexity for J levels is $O(JN\log_2 N)$ which is comparable to the WPT algorithm complexity [20].

C. Wave Atom Transform (WAT)
Wave atoms can be implemented using the wrapping strategy in the frequency plane, along the same line of thought as curvelets [18].

The search for a low redundancy transform is however complicated by the wavelet packet curse, a well documented phenomenon that filter bank ideas provide provably suboptimal time-frequency localization [21].

Wave atom transform is a fast transform, isometric up to round-off errors, and invertible with inversion algorithm of the same complexity. Wave atoms have redundancy 2, i.e., there are twice more wave atom coefficients than samples on the Cartesian grid [18].

The wave atom transform is an $N^2 \log N$ operation, and needs to be applied once to the initial condition. The inverse wave atom transform is also $N^2 \log N$, and needs to be applied once to the final solution [18].

Performance Metrics
For the performance analysis, the metrics like compression ratio (CR), the percentage of root mean square difference (PRD) and visual study of the error signal are used. Error signal is expressed as $e = x_i - \hat{x}_i$ [2], CR is defined as the ratio of the number of bits in the original signal to the number of bits in the compressed signal [2] and PRD is calculated as [15]:

$$PRD = 100 \times \sqrt{\frac{\sum_{i=1}^{N}(x_i - \hat{x}_i)^2}{\sum_{i=1}^{N} x_i^2}} \qquad (1.1)$$

Where x_i and $\hat{x}_i$ are the ith sample of original and reconstructed ECG signal of length N.

Methodology

The proposed technique is implemented in two steps: (i) the transformed coefficients are thresholded using bisection algorithm and (ii) the thresholded coefficients are quantized. The pseudo code for the algorithm is explained as follows [14] [16].

Step 0: Initialization

Get the user-specified PRD (UPRD);

Select the threshold TH in the range [THmin, THmax] where the range may be initialized by [0, *TCmax].

Get the convergence precision ϵ is 1%;

Transform the ECG signal using different transforms.

Step 1: Take a copy of Transformed coefficients (TC) and threshold it by

TH=(THmin+THmax)/2

Step 2: Inverse TC

Step 3: Compute the PRD

Step 4: if (PRD< UPRD)

Then THmin=TH;

Else THmax=TH;

Step 5: if $|PRD - UPRD| / UPRD > \varepsilon$

Then go to Step 1

Step 6: Construct the binary lookup table to represent the zero and non-zero coefficients obtained after thresholding in Step1.

This binary lookup table is encoded using Huffman coding.

Step 7: The non-zero coefficients are quantized using Max-Lloyd algorithm followed by Arithmetic coding.

Step 8: End.

* TCmax - maximum value of Transformed coefficients.

Results and Discussion

The efficiency of the proposed algorithm is tested by experimentation on the well known ECG database, MIT-BIH Arrhythmia [17]. Each record contains 11 bit resolution and 360 Hz a sampling frequency. The duration of each record is 3.0341 min (65536 samples). The ECG signal is transformed using Wave Atom Transform with orthobasis. In the Cosine Packet transform, ECG signal is decomposed to 6 levels. In Wavelet Packet Transform, ECG signal is transformed using coiflet filter and frequency splitting 10.The results are presented in Table I, Table II, Table III and Table IV. Table I, Table II, Table III and Table IV represents the performance of various transforms in terms of CR at fixed PRD=1.0, PRD=1.04, PRD=2 and PRD=3 respectively on different ECG signals. From the numerical results, it is observed that PRD before quantization (BPRD) is nearly equal to PRD after quantization (QPRD). The comparison reveals that Wave atom transform performs better than other transforms in Table I and Table II. It can be concluded from the Table III and Table IV that the Wavelet Packet transform performs better at high UPRD (User defined PRD).

Further, for visual comparison of proposed technique using various transforms, the original and reconstructed signal (normal rhythm MIT-BIH 117 [2]) along with error signal are shown in Fig.1 to Fig.3. The closer look on figures (Fig.1 to Fig.3) reveals that reconstructed signal is identical to original signal.

Table I: Performance of various transforms on different ECG signals at fixed UPRD=1.

[1]UPRD=1, [2]Qbits=12									
Signal	Wavelet Packet			Cosine Packet			Wave Atom		
	[3]BPRD	[4]QPRD	CR	[3]BPRD	[4]QPRD	CR	[3]BPRD	[4]QPRD	CR
103	1.00	1.01	13.68	0.99	1.00	14.11	1.00	1.01	14.37
121	0.99	0.99	35.75	0.99	0.99	36.16	1.00	1.00	37.62
112	1.00	1.00	29.53	0.99	0.99	34.61	1.00	1.00	35.84
122	1.00	1.01	20.82	1.00	1.00	22.26	0.99	0.99	23.22
217	1.00	1.00	14.51	0.99	1.05	17.85	0.99	1.02	18.75
[1]UPRD- user defined PRD [2]Qbits- bits used for quantization [3]BPRD- PRD before quantization [4]QPRD- PRD after quantization									

Table II: Performance of various transforms on different ECG signals at fixed UPRD=1.04.

[1]UPRD=1.04, [2]Qbits=12									
Signal	Wavelet Packet			Cosine Packet			Wave Atom		
	[3]BPRD	[4]QPRD	CR	[3]BPRD	[4]QPRD	CR	[3]BPRD	[4]QPRD	CR
103	1.03	1.03	13.91	1.04	1.05	14.58	1.04	1.05	14.80
117	1.04	1.04	28.02	1.03	1.03	34.31	1.03	1.03	35.26

118	1.04	1.05	19.31	1.04	1.04	22.70	1.04	1.04	23.78
121	1.03	1.04	36.72	1.04	1.04	37.23	1.04	1.05	38.84
210	1.03	1.08	11.06	1.03	1.08	11.84	1.04	1.08	12.10

[1]UPRD- user defined PRD [2]Qbits- bits used for quantization
[3]BPRD- PRD before quantization [4]QPRD- PRD after quantization

Table III: Performance of various transforms on different ECG signals at fixed UPRD=2

[1]UPRD=2, [2]Qbits=12									
Signal	Wavelet Packet			Cosine Packet			Wave Atom		
	[3]BPRD	[4]QPRD	CR	[3]BPRD	[4]QPRD	CR	[3]BPRD	[4]QPRD	CR
103	2.00	2.00	23.03	1.98	1.98	19.54	1.99	1.99	19.61
117	2.01	2.01	39.57	1.99	1.99	33.61	1.98	1.98	34.27
121	1.99	1.99	49.92	1.99	1.99	47.67	1.98	1.98	50.45
116	1.99	1.99	21.08	2.01	2.01	16.56	2.01	2.01	16.93
119	2.00	2.01	27.42	1.99	1.99	20.00	2.00	2.00	20.72
122	2.00	2.00	28.78	1.99	1.99	24.34	1.99	1.99	25.17
123	2.00	2.00	31.98	2.01	2.01	22.37	1.99	1.99	23.71
124	1.98	1.98	36.45	1.99	1.99	27.33	1.98	1.99	28.39
201	2.01	2.01	26.89	1.99	2.00	24.73	1.99	1.99	24.99
205	2.01	2.01	36.23	1.98	1.98	30.29	2.00	2.00	31.46
217	2.00	2.01	19.83	1.98	2.01	18.90	2.01	2.02	19.48
219	1.99	1.99	29.37	1.99	2.00	20.31	1.99	1.99	20.45
220	1.98	1.98	25.79	2.01	2.02	19.53	1.98	1.98	20.06

[1]UPRD- user defined PRD [2]Qbits- bits used for quantization
[3]BPRD- PRD before quantization [4]QPRD- PRD after quantization

Table IV: Performance of various transforms on different ECG signals at fixed UPRD=3.

[1]UPRD=3, [2]Qbits=12									
Signal	Wavelet Packet			Cosine Packet			Wave Atom		
	[3]BPRD	[4]QPRD	CR	[3]BPRD	[4]QPRD	CR	[3]BPRD	[4]QPRD	CR
103	2.99	2.99	29.52	2.99	2.99	21.10	2.98	2.98	21.94
121	2.99	3.00	56.96	3.00	3.00	49.00	2.98	2.98	52.60
116	3.02	3.02	22.20	3.02	3.02	17.76	2.99	2.99	17.92
119	2.99	2.99	29.37	3.00	3.00	20.47	2.98	2.98	21.22
122	2.98	2.98	32.80	2.99	2.99	26.90	3.00	3.00	27.49
124	3.00	3.00	39.35	3.01	3.01	28.19	2.98	2.99	28.91
201	3.00	3.00	39.29	3.01	3.01	30.17	3.00	3.00	30.37
205	3.02	3.02	40.17	2.99	2.99	30.65	2.97	2.97	31.41
217	2.98	2.98	25.19	3.00	3.01	19.72	2.97	2.97	20.06
220	3.01	3.01	28.10	2.98	2.98	20.30	2.97	2.97	20.99
[1]UPRD- user defined PRD [2]Qbits- bits used for quantization [3]BPRD- PRD before quantization [4]QPRD- PRD after quantization									

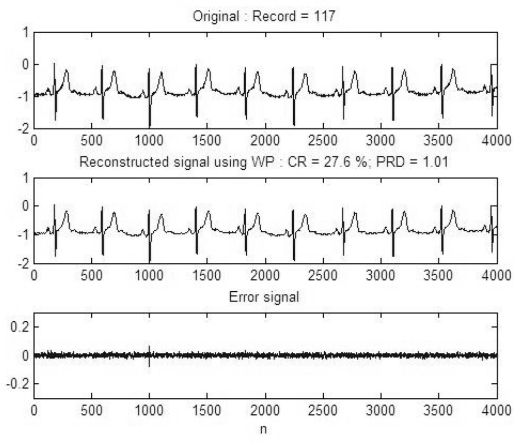

Figure 1: Compressed waveform of record 117 using WPT.

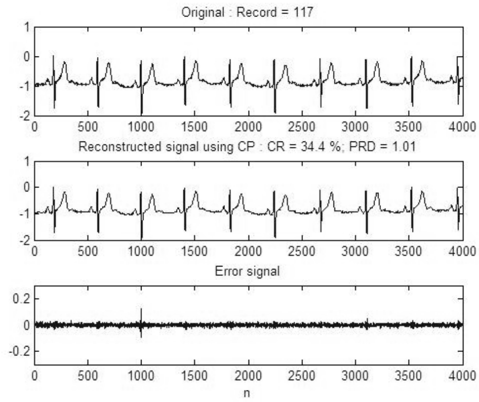

Figure 2: Compressed waveform of record 117 using CPT.

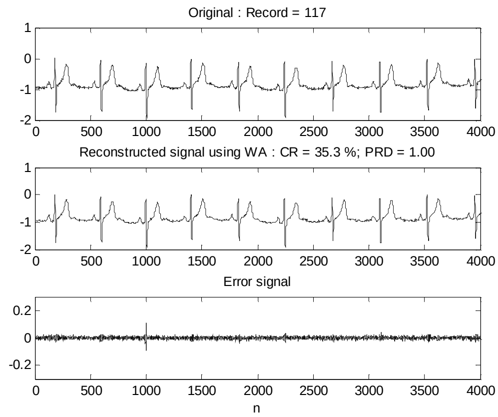

Figure 3: Compressed waveform of record 117 using WAT.

Conclusion

In this paper, impact of Wavelet Packet, Cosine Packet and Wave Atom transforms on ECG compression is studied. A versatile technique for ECG compression is proposed which does not require the knowledge of ECG waveform. We have presented a tunable compression method based on Wavelet Packet, Cosine Packet and Wave Atom transforms. The results are presented on different ECG signals of varying characteristics. The results show that Wavelet Packet transform gives better performance at high PRD whereas Wave Atom transform performs better at low PRD. One can choose Wavelet Packet or Wave Atom transform depending upon the desirable quality. For low quality signal user can choose Wavelet Packet transform and for high quality signal user can select Wave Atom transform. The work presented in this paper may be helpful for the design of efficient ECG compressor.

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