Two Dimensional ECG Compression Using SPIHT and SEC

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Abstract- In this paper, a novel ECG data compression method is implemented based on three main concepts: SPIHT, sub-band energy compression (SEC) method and two-dimensional electrocardiogram (2D-ECG). In the previous work, we used above items and we modified each item in here to achieve better result [1].

Index Terms- two-dimensional ECG (2D-ECG), SPIHT, sub-band energy compression, period and amplitude normalization (PAN)

INTRODUCTION

Techniques for ECG compression can be classified into three categories: 1) direct time-domain methods (e.g., AZTEC, CM, TP, CORTES, and SAPA, FAN), 2) transform methods (e.g., Fourier, KLT, DCT, Wavelet), and 3) parametric techniques (e.g., linear prediction, long-term prediction) [6], [7]. An ECG is a pseudoperiodic signal, which means not periodic in the strict mathematical sense and not completely random signal. By looking at the time evolution of this signal, we can observe a concatenation of similar events or periods which almost never reproduce themselves identically and base on this special behavior several compression methods have been developed such as average beat subtraction with residual differencing, long-term prediction and vector quantization (VQ). Most of these methods are using correlation between adjacent samples in a single cycle (intrabeat dependencies) and not employing correlation between adjacent beats across cycles (interbeat dependencies). Some works have been done to utilize interbeat dependencies .For example, Lee and Buckley [5] used above facts to constructed two-dimensional ECG (2D-ECG) and applied DCT transform to that, or Bilgin and et. al. [7] applied JPEG2000 to the similar constructed image and both works have achieved better results.In our work, we present a new method of ECG compression, using set partitioning in hierarchical trees algorithm (SPIHT) and sub-band energy compression (SEC) method in wavelet domain and we apply SEC and SPIHT to 2D-ECG.We provided simulation results, based on data from MIT/BIH arrhythmia database to show the effectiveness of this approach and in the conclusion, we show a direction of future works.

TWO-DIMENSIONAL ECG

a) General Concepts : In an ECG signal, there are two types of dependencies, which are: the dependencies in a single ECG cycle (intrabeat dependencies) and the dependencies across ECG cycles (interbeat dependencies). An efficient compression scheme needs to exploit both dependencies to achieve maximum compression ratio and minimum errors. The one dimensional ECG sequence needs to be processed to produce a two dimensional matrix. In this matrix, each row contains one or more period of amplitude normalized (PANed) ECG beats, so the intrabeat dependencies can be seen in each row and interbeat dependencies are in each column of the matrix. We used the technique reported in [6] for delineating cycles, and period and amplitude normalization (PAN). Since each ECG cycle can have different time duration, we normalized the time duration of each cycle by using multirate techniques and set it to a constant number *PL* samples in each cycle. This produces beats with a constant period, eliminating the effect of heart rate variability. For this purpose, first each ECG cycle should be detected and then interpolated by resampling the cycle sequnce at *L* times higher than the original sampling rate. Symmetric filters are applied and allow the original data to pass through unchanged and interpolates between samples so that the mean square error between them and their ideal values is minimized.

Let $x(n)$ be the input of an interpolation filter at *L* times higher than the original sampling rate and the impulse response $h_{\text{int}}(n)$. Then the output $y_{\text{int}}(n)$ is given by:

$$y_{\text{int}}(n) = \sum_{k=-\infty}^{k=\infty} x(k) h_{\text{int}}(n - kL) \qquad (1)$$

The factor *L* is chosen to have a high value, so that there would be no error in the next step. After that the interpolated signal, $y_{id}(n)$, is down sampled by factor *M* and the output is:

$$y_{id}(n) = \sum_{k=-\infty}^{k=\infty} y_{\text{int}}(k) h_d(Mn - k) \qquad (2)$$

and $h_d(n)$ is decimation filter. If the signal does not contain frequencies above π / M , there is no need for the decimation filter and downsampling would be enough; thus the changing of the sampling rate will satisfied the Nyquist condition, the original signal $x(n)$ can be retrieved by reverse multirate techniques without any distortions. In Figure 1 we demonstrate PANed 2D-ECG signal. The final output of the system is:

$$y_j(n) = \sum_{k=0}^{k=p_j} x_j(k) h_{\text{int}}(M_j n - kL) \qquad (3)$$

where $x_j(n)$ and $y_j(n)$ are the *n*th samples of the *j*-th input cycles and output of period normalization process, respectively. p_i is the total number of the samples in x_j and M_j is downsampling ratio [6] so :

$$M_j = \frac{L \cdot P_j}{PL} \qquad (4)$$

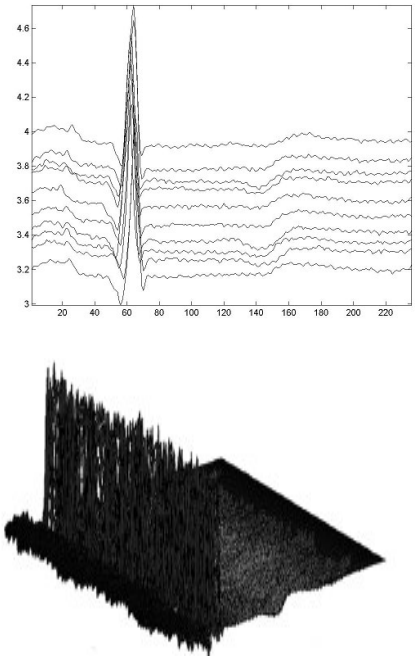

Figure 1: PANed 2D-ECG signal .

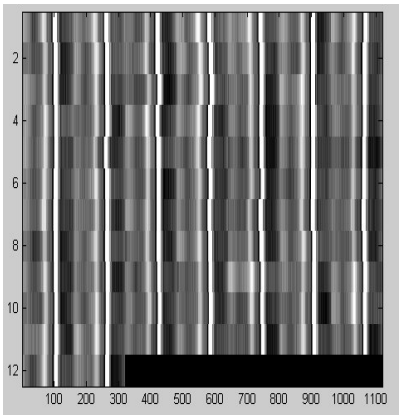

Figure 2: Seven ECG cycles are PANEd and set to the same row.

After the 2D matrix is produced, we should normalize amplitude of that by scaling the value of matrix value from zero to 255.This is performed in order to make beats as similar as possible, and minimizing the variation the beat magnitudes. Now, there is a gray scale image and this is due to 2D-ECG. This process is called cut and align (C&A).

b) The effect of interpolation samples L: As in the Table IV, it is clear that, as we increase the L, the PRD of C&A block decreases and it is because of that, with increase of samples the probability of retrieving the original sample in the down sampling process increases. On the other hand the process time for interpolating samples increases, too and the efficiency of the algorithm for real time using is decreases. In Table IV, it is shown that the C&A PRD of L=1024 and L=2048 are very close to each other, so in our experiment we use L=2048.[1]

c) QRS detection effect: In our experiments, if the detection capability of QRS-detection for aligning R-wave in the certain column increases, the capability of whole process increases and we can achieve more CR or on the other hand, less PRD with a constant CR. If the QRS-detection block does not work correctly or it misses some periods, the CR of the whole process decreases, but we can retrieve all original data if needed. In the other word, the lossless compression is available in this case, too. In the conclusion part, we have shown the results. Table V show the results.

d) Number of cycle in each row: We can set 2 or more ECG cycles in each row of matrix, as in Fig 2. In this case, first, each ECG cycle will be aligned by C&A and then they will be put in row. So, the sizes of all rows are the same. In Table V, the results are shown.[1]

Parent-Children (Offspring) Relationship

The wavelet coefficients can be organized as a set of trees, called wavelet trees, for image coding. In the wavelet domain with the exception of the sub-bands at the lowest resolution level, every coefficient at a given resolution level can be related to a set of coefficients of the same orientation at the next higher resolution level. The coefficient at the low-resolution level is called parent, and all the coefficients at the same spatial location and of the same orientation at the next higher resolution level is called children [3]. The parent-children (sometimes called parent-offspring) relation is:

$$(x, y) \Rightarrow \{ \text{(2x,2y), (2x+1,2y+1), (2x,2y+1), (2x+1,2y)} \}$$

where (x,y) is spatial orientation of parent.

Set Partitioning In Hierarchical Trees Algorithm (SPIHT)

SPIHT is a new coding technique, developed by Said and Pearlman, which order the transform coefficients using a set partitioning algorithm based on the sub-band pyramid. By sending the most important information first of the ordered coefficients, the information required to reconstruct the image is extremely compact. SPIHT is based on three concepts: 1) partial ordering of the image coefficients by magnitude and transmission of order by a subset partitioning algorithm that is duplicated at the decoder. 2) Ordered bit plane transmission of refinement bits ,and 3) exploitation of the self-similarities of the image wavelet transform across different scales. More details on SPIHT algorithm can be find in literatures (i.e.[2],[3]).

Figure 3: 2D-ECG of record 117(left side), 4-stage wavelet transform of 2D-ECG (right side)

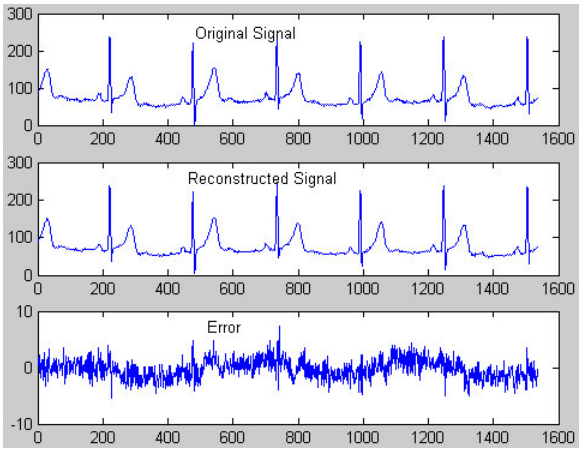

Figure 4: Six beats of the original reconstructed and error signals from a test signal.

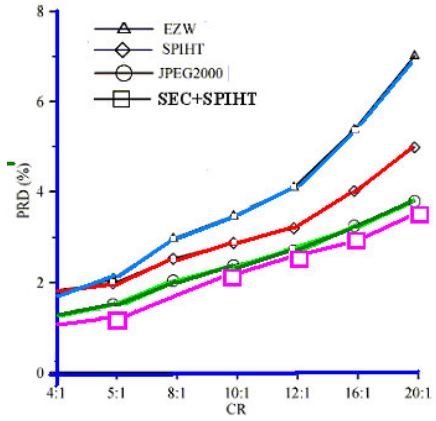

Figure 5:- Comparison of 2D-ECG compression methods

TABLE I:PRD COMPARISION OF DIFFERENT ONE DIMENSIONAL CODING ALGORITHMS

Algorithm	PRD (%)	CR	Signal
SPIHT	1.18	8:1	117
Hilton	2.6	8:1	117
Diohn	3.9	8:1	117
Proposed	***1.01***	8:1	117

TABLE II:AVERAGE TEST RESULTS FOR THE DATASET

CR	4:1	8:1	12:1	24:1
PRD (%)	1.07	1.83	3.24	5.61

TABLE III: QRS DETECTION EFFECT

CR	4:1	8:1	12:1	24:1
PRD (%) **With** Correction of misdetection of ECG cycle	1.07	1.83	2.41	3.69
PRD (%) **Without** Correction of misdetection of ECG cycle	1.14	1.97	2.59	3.91

TABLE IV: THE EFFECT OF INTERPOLATION NUMBER BETWEEN SAMPLES L

	PRD %
L=256	0.00130
L=512	0.00047
L=1024	0.00033
L=2048	0.00031

TABLE V: THE EFFECT OF SEGEMENTATION

SEGMENT NO.	PRD (%)	CR	Signal
1	1.01	8:1	117
2	1.34	8:1	117
5	1.23	8:1	117
7	1.27	8:1	117

Sub-band Energy Compression (SEC)

In here, thresholds are selected based on the EPE [4], that is threshold in wavelet coefficient energy domain as we have :

$$\sum f(t)^2 = \sum W(s,\tau)^2 \qquad (5)$$

The EPE is a percentage quantity that presents a measure of the total preserved energy of a certain sub-band after thresholding with respect to the total energy in the sub-band before thresholding and is defined as

$$EPE_{sub-band} = \frac{E_{sub-band,T}}{E_{sub-band,O}} * 100 \qquad (6)$$

where $E_{sub\text{-}band,T}$ is total energy in the sub-band after thresholding and $E_{sub\text{-}band,O}$ is the total energy in the sub-band before thresholding. The following steps briefly review the algorithm [1], [4].

a) *Calculate the total energy E in the wavelet coefficients W_{ij} in the sub-band*

$$E = \sum W_{ij}^{2}$$

b) *Calculate desired retained energy E'*

c) *Form a sequence W[k] by sorting the magnitudes of wavelet coefficients in descending order.*

d) *Use the following psuedocode to fine the desired threshold*

```
set energy = 0
set k = 0
while energy < E'
  k = k + 1
  energy = energy + ( W[k] )^2
end
threshold=W[k]
```

More details can be find in [1],[4].

Experimental Results

Our resilts arre based on MIT/BIH database and PRD and CR are defined as :

$$PRD\ \% = \sqrt{\frac{\sum_{i=1}^{n} [x_{org}(i) - x_{rec}(i)]^2}{\sum_{i=1}^{n} x_{org}(i)^2}} * 100 \qquad (7)$$

$$CR = \frac{Total\_bits\_in\_orginal\_signal}{HeaderSize + Total\_bits\_in\_reconstructed\_signal}$$

where x_{org} denotes the original data, x_{rec} denotes the reconstructed data , n is the number of samples.Header Size is the number of bits dedicated to image size information, number of beats, scaling factor of each beat and length of each beat

For our purpose, the frame length should be at least 8192 and as a result of Table IV, we have chosen L=2048. We applied four-stage wavelet transform, with 9/7-biorthogonal kernel, to the PANed grayscale image of ECG and then used SEC method and changed the EPE of each sub-band from 20% to 100%, to find out the appropriate EPE of each sub-band for total compression of the image as in Figure 3. Based on the nature of ECG, most of the energy is in the higher sub-bands, especially in horizontal direction, so in this direction; EPE should be higher than other direction in each sub-band to achieve better PRD. Then, SPIHT is applied to *EPE (PANed)*, and bit steam produced by encoder. The bit depth can be set from zero to maximum allowed *m*; so, the more bit depth, the more CR [1].

In Table I we show PRD comparison of different one and two dimensional coding algorithms, respectively,[2],[6]. Our PRD is calculated by averaging all frames PRD; so, it is averaged PRD. As it shows, the proposed PRD is better (less than) the others. In Table II, we show average test results for our dataset that is contains of record number 104, 107, 111, 112, 115, 116, 117,118,119 in the MIT-BIH database. In Figure 4, We compare our method to the other 2D methods those are applied to ECG. We illustrated in Figure 4, six beats of the original, reconstructed and error signals from a test signal to exhibit the effect of compression on the reconstructed signal. In addition to good results in CR vs. PRD challenge, the significant advantage of the proposed method is that generally vital QRS complexes are recovered with a fidelity as good as the other regions in ECG. In Table III, the effect of QRS detection is shown. In addition the distribution of reconstruction error is almost uniform, and thus the morphology of all the components are preserved so, the clinical performance of the method can be considered good because it retains more clinical relevant information with high fidelity [7].

Conclusion

We proposed a novel ECG compression method based on 1) 2D-ECG wavelet transformed approach which utilize both the long-term and short-term correlation of heartbeats signals.,2) SPIHT which brings efficiency, embedded bit stream, exact bit usage control and fast and easy implementation and 3) SEC for more CR regards to better PRD. The results clears that the 2D-ECG compression is better than the 1D-ECG methods, despite of more computation time to produce 2D-ECG. For our future works, we will optimize our codec to work more efficiently with ECG data and will develop multi-component capabilities of the codec to compress multi-channel ECG data. Utilizing this method to other biological signals is our next topic for future researches.

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