ECG Data Compression: A Review

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Abstract-The recent development of biomedical signal processing, information technology and communication has brought a new dimension to the medical world. It is now possible to record an ECG signal with a portable electrocardiograph lightweight and able to transform a micro-computer in electrocardiograph with the possibility of a diagnostic aid for automated interpretation. Applications focusing on portable devices for 24-hour on-line cardiac monitoring are in increasing demand. We are now shifting from a paper-based patient record to a digital one. Many ECG compression algorithms have been researched for optimization with respect to storage capacity and network bandwidth. For this we have to achieve a high compression ratio (CR) result and preserve clinical information (low PRD). Examples of ECG compression algorithms include AZTEC, TP, CORTES, KLT, DCT, DWT. Among these, wavelet transform-based algorithms have received a great deal of attention over the past several years because of their straightforward implementation and efficiency, and their good localization properties in time and frequency domains. This paper gives a bibliographical survey and general backgrounds of research and development in the field of ECG data compression based on over 50 published articles. The collected literature has been divided into many sections so that new researchers do not face any difficulty for obtaining literature in this field.

Key Words: Amplitude-Zone-Time-Epoch-Coding, Coordinate-Reduction-Time-Encoding System, Karhunen-Loève transform, Percent root-mean-square difference, Turning point.

1. Introduction ECG signals, normally consist of 3 to 12 individual leads, each recording 11 bits per sample, 1000 samples per second, and last 24 hours. When converted to a digital format, this single ECG record requires a total of 1.36 gigabytes of computer storage. Considering the 10 million ECGs annually recorded for the purposes of comparison and analysis. Furthermore, the growing need for transmission of ECGs for remote analysis is hindered by capacity of the average analog telephone line and mobile radio. For this purpose, some portable ECG sensing systems associated with wireless data transmission have been developed for real-time ECG signal recording. As the sampling rate, sample resolution, observation time and number of leads increase, the amount of ECG data also increases and so the huge storage capacity is required. Especially, in data transmission, the amount of transmission time increases and it needs more bandwidth for compensation. With all of these limitations, ECG data compression has been one of the most active research areas in biomedical engineering and signal processing. Evaluating an ECG data compression algorithm requires some performance measures to quantify the quality of the reconstructed ECG signals. The most criteria used in the literature are compression ratio (CR) and percent root-mean-square difference (PRD). The CR is computed from the ratio of original file size (in bits) to the length of output bit stream (compressed signal)

\[ CR = \frac{\text{Original samples in bytes}}{\text{Compressed samples in bytes}} \]

The numerical distortion measure used is the percent root-mean-square difference (PRD), which is calculated by

\[ PRD = \frac{\sum (f(i) - \hat{f}(i))^2}{\sum f(i)^2} \]

Where \( f(i) \) is the original signal and \( \hat{f}(i) \) is the reconstructed signal.

2. Methodologies And Analysis

2.1. Time domain techniques These are direct Signal compression techniques where the samples of the signal are directly handled to provide the compression. Coding by time-domain methods is based on the idea of extracting a subset of significant signal samples to represent the signal. The reconstruction, in the decoder, is done by performing linear interpolation between the retained samples. In 1968, J. R. Cox [1], proposed an Amplitude-Zone-Time-Epoch-Coding (AZTEC) algorithm. AZTEC takes raw ECG data and replaces sequences of sample points with plateaus and slopes. For signals sampled at 200 sps with a 12-bit analog-to-digital converter, AZTEC’s average data-compression ratio is observed to be about 80 percent (5 : 1) and PRD of 31%. In 1978, W. C. Mueller [2], suggested a new turning point (TP) algorithm. This reduces the amount of data by 50 percent (2-to-1 reduction) and and PRD of...

2.2. Transformation compression techniques

These methods mainly utilize the spectral and energy distributions of the signal. Generally this means processing the input signal by means of some transform, and properly encoding the transformed output. Signal reconstruction is achieved by an inverse transformation process. In 1986, B. R. Shankara Reddy [12], applied an approach based on the method of Fourier descriptors (FDs) technique for ECG data compression. In 1990 C. P. Mammen [13], presented a data-reduction algorithm m-AZTEC, which is a multichannel extension of the amplitude zone time epoch coding (AZTEC) algorithm. He also used a scheme based on vector quantization (VQ) to code correlated multichannel signals. VQ is a coding technique, which has been also employed to compress image and speech signals [14]. Thus VQ-coded m-AZTEC achieved a compression-factor of 2.0 over m-AZTEC, yielding a net compression factor of 8.6. In 1993, A. Enis Cetin[15], presented a new multilead ECG data compression technique. In this technique sample of the standard ECG lead signals are first linearly transformed. Then, resulting transform domain signals are compressed using various coding methods, including multirate signal processing and transform coding methods. As a linear transformer, both the optimum transform, Karhunen-Loeve, and a suboptimun transform, DCT are used. In 1996, Salvador Olmos[16], proposed the ECG compression strategy based on Karhunen-Loeve transform technique. The KLT has been applied in two different ways: firstly, using the entire beat as pattern vector of the KLT, and the second one using independent signal subwindows: P wave, QRS complex and ST-T complex. The latter method (KLW) achieves better compression ratio of 17.2 and mean squared error (MSE) value of 0.3%. In 1995, Adrianus Djoohan [17], proposed the ECG compression strategy based on Discrete symmetric wavelet transform [18], optimal bit allocation and Huffman coding. Using this method, he achieved better compression ratio of 8 to 1 with PRD =3.9 % for 117 in the MIT-BIH Arrhythmia Database, in contrast to the AZTEC compression ratio of 6.8 to 1 with PRD =10.0 % and the fan algorithm compression ratio of 7.4 to 1 with PRD =8.7 % . In 1997, Michael L. Hilton[19], proposed the ECG compression strategy using Wavelet and wavelet packet-based compression algorithms based on embedded zero tree wavelet (EZW) coding. The algorithms are of low computational complexity $\delta(n)$ and $\delta(n \log_{2} n)$ respectively. The wavelet packets of Coifman and Meyer [20] are a generalization of the wavelet transform that allow for arbitrary tree-shaped bandpass filterings and can be adapted to the characteristics of the particular signal being analyzed. Hilton achieved better compression ratio of 8:1 with PRD =2.6% for 117 in the MIT-BIH Arrhythmia Database. The resulting PRD’s by wavelet packet were consistently higher (worse) for the same signal when compared with those of the plain wavelet coder. In 1997, Baohua Wang [21], proposed Finite-State Vector Quantization and directly employed VQ to compress a single-channel ECG signal because the error the m-AZTEC algorithm yields is relatively large and its anti-noise capability is weak. In 1998, Jie Chen[22], proposed the ECG compression strategy based on orthonormal wavelet transform and an adaptive quantization strategy, by which a predetermined percent root mean square difference (PRD) can be guaranteed with high compression ratio and low implementation complexity. He achieved better compression ratio of 8.31 to 1 with PRD =1.07%. In 2000, Shao-Gang Miaou[23], proposed a new adaptive vector quantization (AVQ) scheme to exploit this correlation for multichannel ECG data compression. The proposed approach has better coding performance than using single channel approach by 1.26 & 0.1 times. In 2000, E. Berti[24], presents an electrocardiogram ECG data reduction method based on Walsh spectrum double

“Table 1. Average Test Results For Dataset”

<table>
<thead>
<tr>
<th>CR</th>
<th>4:1</th>
<th>5:1</th>
<th>8:1</th>
<th>10:1</th>
<th>12:1</th>
<th>16:1</th>
<th>20:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRD</td>
<td>1.19</td>
<td>1.56</td>
<td>2.46</td>
<td>2.96</td>
<td>3.57</td>
<td>4.85</td>
<td>6.49</td>
</tr>
</tbody>
</table>

In 2001, Shaou-Gang Miao[27], propose a MC adaptive vector quantization (MC-AVQ) algorithm, where AVQ is performed on each channel and across channels to exploit the correlation within a channel and across channels. VQ often suffers from the mismatch problem, i.e., the codebook generated from a set of training data is not suitable for the test sets. Adaptive vector quantization (AVQ) is designed to solve this problem by updated AVQ codebook according to changing characteristics of the test set. In 2002, Bashar A. Rajoub [28], used discrete wavelet transform (DWT) to compress ECG signals. The ECG signal is first preprocessed by normalization, mean removal, and zero padding. Normalization and mean removal guarantees that all significant coefficients be less than one. Thus, reducing the number of bits needed to represent each coefficient. Zero padding reduces the reconstruction errors at both ends of the compressed signal. Thresholding of the wavelet coefficients is done based on a desired energy packing efficiency (EPE).

“Table 2. PRD Comparison”

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>PD R%</th>
<th>CR</th>
<th>Signal</th>
<th>Sampling R(HZ)</th>
<th>Bits/sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPIHT</td>
<td>1.18</td>
<td>8:1</td>
<td>MIT-BIH 117</td>
<td>360</td>
<td>11</td>
</tr>
<tr>
<td>Hilton</td>
<td>2.6</td>
<td>8:1</td>
<td>MIT-BIH 117</td>
<td>360</td>
<td>11</td>
</tr>
<tr>
<td>Dohn</td>
<td>3.9</td>
<td>8:1</td>
<td>MIT-BIH 117</td>
<td>360</td>
<td>11</td>
</tr>
</tbody>
</table>

In 2004, M. Blanco-Velasco[30], presented an easy to use and efficient ECG compression scheme based on an M-channel maximally decimated filter bank with a parallel structure [31] that guarantees the quality of the retrieved signal. This method utilises a nearly-perfect reconstruction cosine modulated filter bank to split the incoming signals into several subband signals that are then quantised through thresholding and Huffman encoded. He achieved compression ratio of 8.24 with percent root mean square difference (PRD) of 1.176% for MIT-BIH 117 signal. In 2008, M. Sharafat Hossain[32], proposed algorithm for an ECG compression system using wavelet transform and thresholding technique based on energy packing efficiency (EPE). As the WT decomposes the ECG signal into multiresolution bands, a multi-level thresholding strategy based on EPE is applied by him. The algorithm can be tuned to required compression ratio and PRD by selecting thresholds based on a desired EPE. He achieved an average compression ratio of 13.57 with percent root mean square difference (PRD) of 4.87 for a large set of normal and abnormal ECG signals extracted from MIT-BIH database.

“Table 3. PRD Comparison”

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>PDR %</th>
<th>CR</th>
<th>Signal</th>
<th>Sampling R(HZ)</th>
<th>Bits/sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWT</td>
<td>1.06</td>
<td>22.19:1</td>
<td>MIT-BIH 117</td>
<td>360</td>
<td>11</td>
</tr>
<tr>
<td>DWT</td>
<td>1.95</td>
<td>23:1</td>
<td>MIT-BIH 119</td>
<td>360</td>
<td>11</td>
</tr>
<tr>
<td>ASEC[29]</td>
<td>5.5</td>
<td>21.6:1</td>
<td>MIT-BIH 119</td>
<td>360</td>
<td>11</td>
</tr>
</tbody>
</table>

In 2009, N. Boukhennoufa[33], proposed method combines the adapted SPIHT(Set Partitioning In Hierarchical Trees) method with VKTP (Vector K-Tree Partitioning) coder[34] and achieved to increase the performance of the compression methods and to reduce the reconstruction error provided. He achieved better compression ratio of 8.11 to 1 with PRD =1.8% for 117 in the MIT-BIH Arrhythmia Database . In 2009, Gyu - Hyeok Jeong [35], presented an improved wavelet compression algorithm is proposed for electrocardiogram (ECG) signals which is combined with the lifting wavelet transform (WT) and the dynamic multi-stage vector quantization (MS-VQ). In 2009, Iulian B. Ciocoiu[36], proposed a novel compression scheme based on combining DWT analysis with a space-scale selective mask constructed following retina-like foveation principles. Foveation enables the definition of a proper mask that will modulate the coefficients given by the Discrete Wavelet Transform of an ECG record. The mask is spatially selective and provides maximum accuracy around specific regions of interest. Subsequent denoising and coefficient quantization is further combined with a lossless compression technique in order to provide high compression ratios at low reconstruction errors. He achieved better compression ratio of 5.55 to 1 with PRD = 0.52% for 117 in the MIT-BIH Arrhythmia Database. In 2010, Ataollah Ebrahimzadeh[37], has performed...
a different thresholding method using the Three-Level Quantization and used various wavelets and both EZW & Huffman encoding for a better compression. He have evaluated the effect of signal length and iterations of quantization on the compression ratio (CR). In low iterations, PRD & CR increased and CC (correlation coefficient) decreased, in high iterations of quantization values of PRD, CR decreased and CC increased.

In 2008, Emna Zoghlami Ayari [49] applied algorithm based on template model fitting by using a nonlinear least square optimization procedure. His proposed a low computational cost model having only 12 parameters to fully represent the ECG signal. In 2008, Ibrahim Khalil[50], decomposed ECG data first using wavelet packet decomposition (WPD), and then low frequency components can be given highest priority before being transferred over wireless networks. His results show both high and medium priority ECG packets suffer no delays which is very beneficial for ECG transmission system over bandwidth constrained wireless networks. In 2006, Byung S. Kim[51], proposed a wavelet transform-based ECG compression algorithm with low delay characteristics for instantaneous, continuous ECG transmission suitable for telecardiology applications over wireless network. His proposed algorithm reduces the frame size as much as possible to minimize delay, whereas maintaining reconstructed signal quality without affecting the diagnostic characteristics of the ECG signals at the receiver end.

4. Conclusion
ECG data compression has become in the last 40 years one of the most challenging topics in Biomedical signal processing. However, there is still a continual need for the advancement of algorithms adapted for ECG data compression. This paper is an effort for an overview of ECG data compression, with a bibliographic survey of relevant background, practical requirements, the present state, and techniques. The citations listed in this bibliography provide a representative sample of current thinking pertaining to ECG data compression. The necessity of better ECG data compression methods is even greater today than just a few years ago for several reasons. The quantity of ECG records is increasing by the millions each year, and previous records cannot be deleted since one of the most important uses of ECG data is in the comparison of records obtained over a long range period of time. The ECG data compression techniques are limited to the amount of time required for compression and reconstruction, the noise embedded in the raw ECG signal, and the need for accurate reconstruction of the P, Q, R, S, and T waves. With the current wireless technology the uplink bandwidth to transfer ECG data is limited and hence more algorithms for ECG Compression and its real-time transmission is yet to be explore.

### Table 5. The PRD, CR Comparison Of Different Coding Algorithm For MIT-BIH 117

<table>
<thead>
<tr>
<th>ALGORITHMS</th>
<th>PRD%</th>
<th>CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Djohn[17]</td>
<td>3.9</td>
<td>8</td>
</tr>
<tr>
<td>Hilton[19]</td>
<td>2.6</td>
<td>8</td>
</tr>
<tr>
<td>Chen[22]</td>
<td>1.07</td>
<td>8.31</td>
</tr>
<tr>
<td>SPIHT[38]</td>
<td>1.18</td>
<td>8</td>
</tr>
<tr>
<td>Benzid[39]</td>
<td>2.55</td>
<td>16.24</td>
</tr>
<tr>
<td>JPEG2000[40]</td>
<td>1.03</td>
<td>10</td>
</tr>
<tr>
<td>WT&amp;Huffman[41]</td>
<td>3.2</td>
<td>9.4</td>
</tr>
<tr>
<td>Sec&amp;SPIHT[42]</td>
<td>1.01</td>
<td>8</td>
</tr>
<tr>
<td>SPIHT&amp;VQ[43]</td>
<td>1.45</td>
<td>8</td>
</tr>
<tr>
<td>N. Boukhennoufa[33]</td>
<td>1.18</td>
<td>8.11</td>
</tr>
<tr>
<td>A.Ebrahimzadeh[37]</td>
<td>0.97</td>
<td>13.92</td>
</tr>
</tbody>
</table>

3. Recent Work
In 2010, Cheng-Tung Ku [44], proposed his 1-D RRO-NRPWT, a new multivariable quantization algorithm to overcome the problem of Word-length-growth (WLG) effect that arises in online applications. For efficient reconstruction quality control, he Combining the reversible round-off linear transformation (RROLT) theorem[45] and 1-D nonrecursive discrete periodic wavelet transform (NRDPWT) [45]. In 2009, Vibha Aggarwa[47], applies a new quality controlled Discrete Cosine transform (DCT) and Laplacin Pyramid based compression method for electrocardiogram (ECG) signal. The transformed coefficients are thresholded using the bisection algorithm in order to match the predefined user specified PRD within the tolerance. His results show that Laplacian Pyramid provides better CR over 2.5 PRD value on the normal rhythm (MIT-BIH 117) as compared to DCT, whereas on abnormal rhythm (MIT-BIH 232) the behavior of the transforms is opposite. In 2009, Hyejung Kim[48], proposed quad level vector (QLV) for the ECG holter system. He achieved average compression 16.9:1 with 0.64% PRD value and the encoding rate is 6.4 kbps. The accuracy performance of the R-peak detection is 100% without noise and 95.63% at the worst case with −10-dB SNR noise. His proposed compression techniques reduced the processing cost by 45.3%.
5. Reference


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