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ECG Compression using Modified Huffman Coding and Efficient QRS Detection

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ABSTRACT

The ECG signal data plays a major role for the purpose of heart disease diagnosis. These signals support the medical experts to diagnose the heart disease. In order to transmit these signals to the medical expert side, proper compression mechanism is needed where the vital signal peaks are preserved and the quality of the decompressed signal is not compromised. But the signal compression becomes a major issue and different methods are available to address this issue. In order to resolve this issue in an effective manner, a powerful and well organized compression system is presented in this paper. The compression system comprises of three optimistic phases. First phase removes the baseline wander using the discrete wavelet transform. Second phase detects the QRS complexes using the improved dynamic thresholds and the detection of QRS complexes is an essential portion for compression. Then the Cut and Align Beat technique based 2D array signal is decomposed using the 2D-DWT. Finally the actual compression is carried out using the Modified Huffman Coding through which the signal quality is maintained with (lossless) minimized loss of compression.

Keywords: Electrocardiogram (ECG), ECG signal, Baseline wander, discrete wavelet transform, QRS complex, dynamic threshold, Modified Huffman Coding.

1. INTRODUCTION

The Electrocardiogram (ECG) signals are useful for the purpose of observing and diagnosing the disease of the patients. So it is essential to store the ECG signal without any defect. This process of documentation of the ECG signals generates large data which in turn increases the number of channels, various sampling rates, time and so on [1]. This becomes a problem for storing the ECG signal which results in the necessity of fast transmission and the process becomes economically high. Hence the data compression provides the solution for the fast transmission, storage problem and better in economical wise also. Considering the real time ECG compression, the computation time proves better when compared with the other methods of storage minimization. This compression proves efficient when applied in the telemedicine, database management and transmission [2].

The key idea of ECG signal compression is to show the signal image with reduced number of bits. This compression supports the image transmission and image processing. Considering various medical sources which are using signal as its data, the Electrocardiogram (ECG) has the increasing expectation in compression process. Many types of ECG recording are available which produces huge ECG signal. These signals are recorded and stored in the medical database which consists of hundreds of thousands of ECG signals used for evaluation and diagnosis purpose to the medical experts [3].

Likewise the paper proposes the compression method with new combination of techniques. The ECG signal is preprocessed using discrete wavelet transform which removes the baseline wandering, improves the signal to noise ratio (SNR) and preserves the actual shape of the ECG signal particularly the Q, R, S peaks without disturbing the other smooth signals. The compression needs the reduced signal with the significant portion like QRS complexes. Therefore the QRS complexes detection is performed using the improved dynamic threshold method which is an enhanced version of adaptive quantized threshold method. Then the signal is transformed into 2D array signal using the Cut and Align techniques and the 2D-DWT is used to decompose the 2D array signal. Finally the compression is performed using the Modified Huffman coding Technique after the quantization and thresholding process.

2. RELATED WORK

Many compression algorithms are present to compress various data formats. The paper investigates such algorithm that provides lossless compression and evaluates the performance of those algorithms. This investigation ends in highlighting the specific algorithm that works well in data compression. This paper [4] also discusses the different areas of the image processing in which the data compression is applicable. This also discusses the merits and demerits of the compared techniques.

The Modified Set Partitioning in Hierarchical Tree (M-SPIHT) algorithm [5] is proposed for the ECG signal compression. The peak signal to noise ratio (PSNR) and mean square error are computed in order to measure the image quality in addition with the visual appearance. Finally the ECG compression attains elegant high speed and low bit rate. The proposed method achieves better visual quality and low bit rate when compared with the real SPIHT compression method.

The computerized applications nowadays are in need of data compression where various algorithms are presented to compress the data into different formats.

The author [6] investigates different data compression algorithms which are using the ECG image strip and validate their performance. The result of this discussion shows that the proposed system for compression exhibits better performance than the existing compression techniques.

The traditional first derivative based squaring function termed as Hamilton-Tompkins and QRS detection using the Hilbert transform-based methods are evaluated and introduce a new method with improved detection threshold [7]. The Hamilton-Tompkins has attained the greater accuracy but it drops down when the time error rate is high. Likewise the Hilbert transform-based methods also had the problem in magnitude spectrum. Hence the combination of these two methods are presented here which even though gives slower performance, it does not in need of human intervention to determine the threshold point. The combination of these two mechanisms identifies the abnormalities in the signal quickly that will be considered for further use.

The author [8] improvises the wireless body sensor networks (WBSN) that increase the compressed sensing signal potential and also renders the low complexity energy-efficient compression. This compression extracts the information that gives the communication technology for providing the quality of care, improved personalization, early prevention and diagnosis. Finally the proposed CS based ECG compression is compared with the DWT ECG compression. The proposed method beats the DWT method where the CS based method grows in terms of overall energy efficiency.

In order to examine the real identity of the objects or humans in the image, the Face Recognition (FR) has attained much importance. But the major issue in the FR is that the compression techniques. Many such techniques have been introduced recently. Therefore the author [9] proposes the 2D-Discrete Fractional Fourier Transform (2D-DFFT) for facial image compression in an efficient way. The proposed technique for facial image compression is compared with the previous method to evaluate its performance and efficiency.

3. METHODOLOGY

The proposed powerful and well organized compression system is depicted in the figure 1. Initially the ECG signals are taken as input and given to the baseline wander removal section where the discrete wavelet transform is used to remove the base wander. Once the preprocessing is done, the precaution steps to perform compression have to be done first. The compression requires the signal with reduced dimensionality.

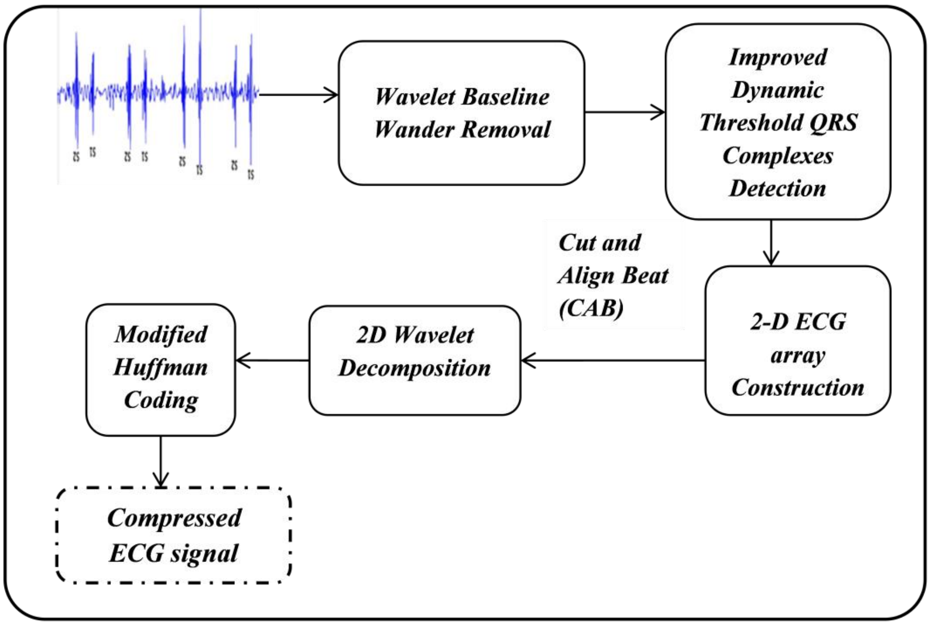

Figure 1 System Architecture

QRS complexes are of higher significance for the process of compression. Therefore the QRS complexes detection is unavoidable in the compression process. The QRS complexes detection is performed using the combination of adaptive quantized threshold and the dynamic threshold method together called as improved dynamic threshold. The QRS complexes are then transformed into the 2D array signal using the Cut and Align Beat methods and then decomposed using the 2D-Discrete Wavelet Transform (DWT). Finally the decomposed signal has undergone the process of thresholding and quantization and compressed using the Modified Huffman Coding Technique.

a) Wavelet Baseline Wander Removal

Baseline wander is simply an important meander generates from the ECG baseline due to the patient body movement, improper electrode site preparation, breathing, bad electrodes, and so on [10]. In order to get the clear information from the ECG signal and to improve the characteristics of ECG signal, this type of preprocessing steps are necessary. Therefore, the baseline wander removal is performed here with the support of Discrete Wavelet Transform [11]. It also assumes that the baseline spectrum appears below the ECG signal spectrum. So, as the scale is changed in the decomposition process, the energy concentration of baseline spectrum with the corresponding time-scale is not changed. In addition, as the scale changes, the ECG signal energy also decreases. At last, the baseline wander is possible to be estimated using the inverse wavelet transform of approximation coefficients during the detail coefficient energy reaches the local minima in specific level of decomposition.

The baseline wander removal of ECG signal is represented as

$$S(n) = \sum_{k=-\infty}^{\infty} c_j(k)\phi_{j,k}(n) + \sum_{j=1}^{J}\sum_{k=-\infty}^{\infty} d_j(k)\psi_{j,k}(n) \quad (1)$$

where $\phi_{j,k}(n)$ is the scaling function while $\psi_{j,k}(n)$ is the wavelet function, $c_j(k)$ denotes the scaling coefficients and $d_j(k)$ represents the wavelet coefficients. The scaling and wavelet functions are represented as

$$\phi_{j,k}(n) = 2^{j/2}\phi(2^j n - k) \quad (2)$$

$$\psi_{j,k}(n) = 2^{j/2}\psi(2^j n - k) \quad (3)$$

b) Improved Dynamic Threshold QRS Complexes Detection

There are three major components that comprise in the ECG signal namely T-wave, P-wave and QRS complexes. The QRS complexes are not always the strongest one, because they may vary depending on time. Therefore the characteristics of P and T-waves may be homogeneous with the QRS that leads to the problem in QRS detection. Hence it is necessary to detect the QRS complexes with more precision that helps in ECG signal compression. Once the Baseline Wanders are removed from the original ECG signal, then the QRS detection is important to compress the ECG signal. The proposed work detects the QRS signal [12] from the noise removed ECG signal using the Improved Dynamic Threshold (IDT) method as follows:

(i) The mean is computed and subtracted from the ECG signal.

(ii) The moving average (speed) $FG1$ of the ECG signal is calculated using the Eq. (1) with the rectangular slides of 21 sample points ranging from$(n - 10)\ to\ (n + 10)$.

$$FG1(n) = \frac{1}{21}\sum_{i=n-10}^{n+10} G1(i) \quad (4)$$

$$n = sample\ values\ og\ ECG\ signal$$

(iii) The term $pre_F_q$is the product of the filtered ECG signal $S(n)$ with the moving average filter $FG1$ in order to improve the QRS complexes.

(iv) The final QRS complexes signal detection is obtained as fix the pre_F_q whose amplitude value is greater than the dynamic threshold. the final QRS complex signal is defined as

$$pre_{F_q(n)} = \begin{cases} pre_{F_q}(n), pre_{F_q}(n) > T \\ 0\ , otherwise \end{cases} \quad (5)$$

$$T = sd(pre\_F_q\ ) + mean(pre\_F_q\ ) \quad (6)$$

where dynamic threshold T is the sum of the standard deviation and the mean of the final desired QRS signal.

(v) Once the QRS are detected, the boundaries of the QRS complexes have to be fixed. This done by marking the pulses $C_Q(n)$ of unit amplitude in the detected QRS region by using the Eq.(7)

$$C_Q(n) = \begin{cases} 1, & F_q(n) > 0.01 \\ 0, & otherwise \end{cases} \quad (7)$$

where $C_Q(n)$ denotes one whole pulse in QRS peaks

(vi) The QRS boundaries are marked successfully; the number of QRS peaks is counted by finding the absolute value of the difference of the pulses $C_Q(n)$ and is referred as Onset/Offset indexes.

$$\text{Onset Offset indexes} = \text{find}\left(\text{abs}\left(\text{diff}\left(C_Q(n)\right)\right)\right) \quad (8)$$

(vii) From the Eq. (8), the R peak and its amplitudes are detected and stored in a new array. Then the number of QRS peaks is found by counting the number of values in the array.

(viii) This sequence of 8 steps is repeated till all the missed QRS complexes are found.

c) Cut and Align Beat (CAB) 2-D ECG array Construction

In order to transform the 1-D ECG signal to 2-D array, initially the heart beat periods which in turn called as R-R interval (interval between two R-peaks) is identified using the detected QRS complex. Each row of an array has one or more heartbeat period (R-R interval), hence the relation between two beats can be seen through the row whereas the relation (dependencies) of a single beat can be seen through each column of the matrix. To start the process of Cut and Align Beat [13], the ECG signal is cut into “n” samples. Since the ECG signal does not maintain the period regularity, it becomes an issue to construct the 2-D array. Therefore the process of general resampling and normalization is needed to apply to the ECG signal at each cycle maintaining the constant number of samples in each cycle. Thus the 2-D array of the ECG signal is constructed and scales the array value in order to normalize the amplitude of the R-peaks. This process of Cut and Align Beat (CAB) technique provides the output as 2-D ECG signal and the gray scale image.

d) 2-D Discrete Wavelet Transform based ECG signal compression

This process de-correlates visual and pixel information of the image. The gray scale image of the signal is given to the 2D-DWT [14] where in the filter banks are used. First, the samples are processed under horizontal filters and then by the vertical filters. The output of the horizontal filter is the 1D-DWT and the output of the vertical filter is the 2D-DWT. In the process of 2D-DWT, the image function $f(m,n)$ is decomposed into four sub bands which consists of one scaling function $\phi(m,n)$ and three wavelet functions namely $\psi^v(m,n)$, $\psi^d(m,n)$ and $\psi^h(m,n)$. Let this scaling and analysis function associated with the 2D-Multi Resolution Analysis (MRA) and the synthesis and analysis function can be denoted by using the following equations.

$$F_{\phi}(j_0, a, b) = \frac{1}{\sqrt{MN}} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} f(m, n) \phi_{j_0,a,b}(m, n) \quad (9)$$

$$F_{\psi}(j, a, b) = \frac{1}{\sqrt{MN}} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} f(m, n) \psi^{i}{}_{j_0,a,b}(m, n) \quad (10)$$

where $i = (h, v, d)$

Using these two coefficients of the signal in the decomposition process, the 2D-Discrete Wavelet Transform (2D-DWT) signal decomposition is termed as

$$f(m,n) = \frac{1}{\sqrt{MN}} \sum_{m} \sum_{m} F_{\phi}(j_0, a, b) \phi_{j_0,a,b}(m, n) + \frac{1}{\sqrt{MN}} \sum_{i=h,v,d} \sum_{j=j_0}^{\infty} \sum_{m} \sum_{m} F^{i}{}_{\psi}(j, a, b) \psi^{i}{}_{j,a,b}(m, n) \quad (11)$$

Modified Huffman ECG Signal Compression

The obtained pixel and visual information of the image from the wavelet decomposition process are processed by the thresholding function where the image is converted into binary format (highlighting the significant portion of the ECG signal) that helps to visualize the significant portion in the image clearly. Then quantization process is performed in the image where the significant portion of the image is extracted and through which the pixels are reduced. Therefore the compression process begins from the quantization process. Then the actual compression process is done by utilizing the Modified Huffman Coding [15] which works as follows and depicted in the figure 2.

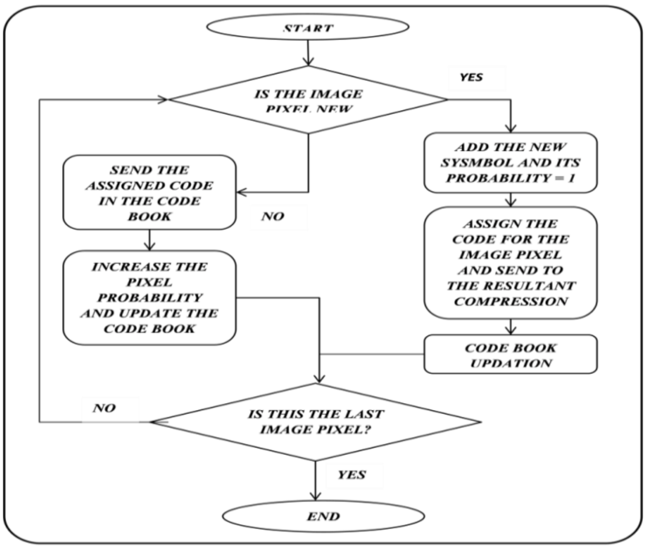

Figure 2 Modified Huffman ECG Signal Compression

The Huffman coding has the main principle of assigning the long code words to the input symbols with low probabilities and assigning short code words for the input symbols with high probabilities. But the modified Huffman coding assigns the fixed code words for all the input signal initially. Then the probability will do increase whenever the symbol (image pixel) appears. The coding process starts with assigning the fixed code word for all the image pixels.
Step 1: The input image pixel is checked whether it is available in the code book where the compressed portion of the image resides.
Step 2: if it is available, increase the probability of the pixel by one, send the assigned code to the compression result and update the probability of the pixel in the code book.
Step 3: if the pixel is new to the code book, then the new symbol is added to the code book, increase the probability by one and send the assigned code to the compression.
Step 4: check whether the pixel is last in the whole image, if yes, the process ends, else process the next pixel of the ECG signal.

Likewise the redundant code is removed and the whole ECG signal with the compressed code is summed which gives the compressed ECG signal as result.

RESULTS AND DISCUSSION

Many mechanisms have been introduced for the ECG signal compression. But still there exist some drawbacks in either compression time or in the methods used. Therefore the existing Huffman coding is taken and implemented with some modifications and hence named as Modified Huffman Coding.

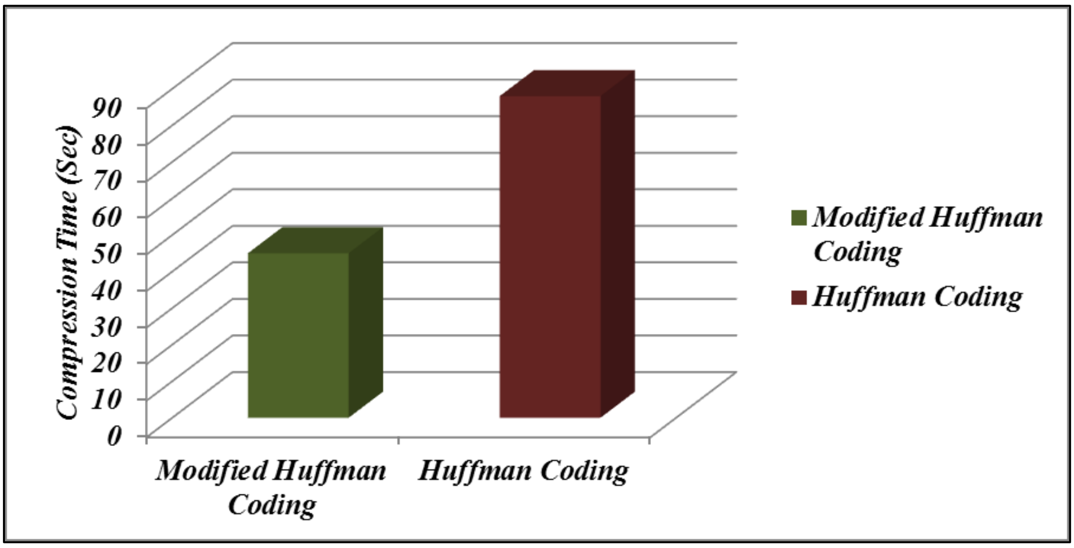

Figure 3 Compression Time

The figure 3 shows the comparison between Huffman and Modified Huffman Coding in terms of compression time. This shows that the Modified Huffman Coding based compression of ECG signal compresses the image in less time with better efficiency.

The effectiveness of any compression method is validated by using the parameters such as Compression Rate (CR) and Percent Root Mean Square Difference (PRD). The compression ratio is determined by using the following formula and the performance of the compression method wiil be higher when the CR value is higher.

$$CR = \frac{Original\ ECG\ data\ file\ size}{Compressed\ ECG\ file\ size} \quad (12)$$

Here, the proposed method gives higher CR value than the other existing methods. The CR value of the proposed reaches nearly 95%.

In order to measure the error loss, the Percent Root Mean Square Difference (PRD) has to be calculated. This is the difference between the compressed signal and the original signal. The PRD measure is computed as

$$PRD = 100\ X \sqrt{\frac{\sum_{i=1}^{n} y_i - \overline{y_i}}{\sum_{i=1}^{n} {y_i}^2}} \quad (13)$$

If the PRD value is low, then the reconstructed signal is closer to the original signal. Thus the proposed system has the lowest PRD value.

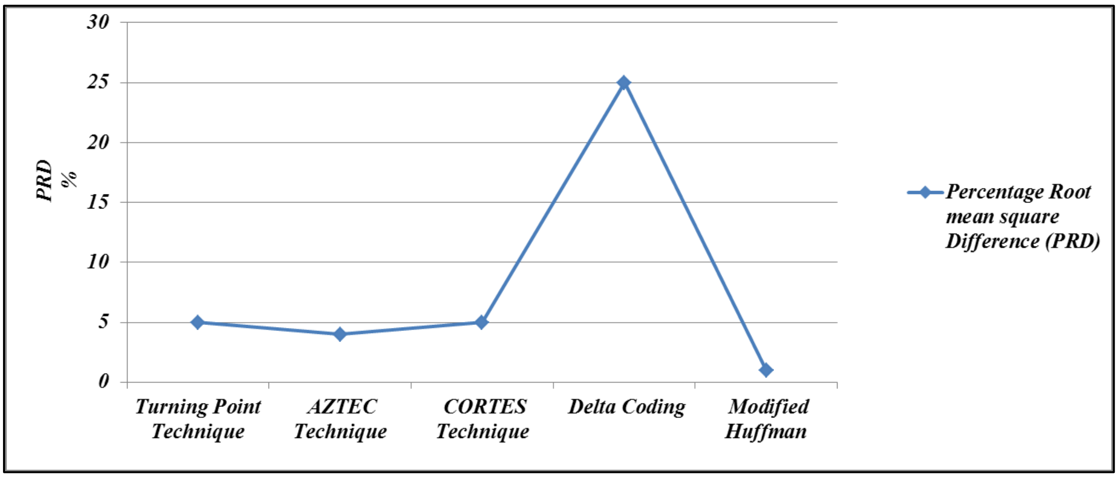

Figure 4 PRD value comparison of proposed with other algorithms

The PRD value is calculated by using the existing compression methods and those values are compared with the proposed methods based on 2D-DWT and the Modified Huffman Coding compression. Figure 4 shows that the proposed renders less PRD value when compared with all the existing methods.

CONCLUSION

In this paper the Electrocardiogram (ECG) signals are compressed based on the Discrete Wavelet Transform (DWT) and Modified Huffman Coding. The ECG compression is very important for monitoring the patients and early diagnosis of heart diseases from the remote place. The preprocessing stage removes the baseline wander which provides distortion to the signal image. This preprocessing and the decomposition process are done using the 2-Dimensional Discrete Wavelet Transform (2D-DWT). The QRS complexes detection is performed by using the Improved Dynamic Threshold method. Then the 2D transformation of the ECG signal is done using the Cut and Align Beat (CAB) technique. Next the Huffman coding is modified and named as Modified Huffman Coding compresses the decomposed signal with higher compression rate. Most of these compression methods are compromised in their decompression rate and the quality. But the proposed method improves the quality rate and obtains less PRD value.

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