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A Survey on ECG Analysis using EMD Technique

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Abstract— QRS detection model depends upon the Empirical Mode Decomposition. These techniques are essential to check the size of data to be transmitted without losing the clinical information. EMD decompose signal in to IMFs. In the study three different methods based on EMD is compared. In all three methods three different techniques are used, so their results are differ.

Keywords—EMD,Beat Detection ,QRS Complex,PGC, ECG.

I. INTRODUCTION

The ECG is a one of the important physiological signal which depicts the electrical activity of a heart. ECG processing is a topic of great interest in the scientific community because based on the ECG's a diagnosis is done for detecting abnormalities in the heart functioning [1]. Basically, a data coding algorithm seeks to minimize the number of code bits stored by reducing the redundancy present in the original signal. The design of data compression schemes therefore involves trade-offs among various factors including the degree of compression, the amount of distortion introduced (if using a lossy compression scheme) and the computational resources required to compress and uncompress the data. To deal with the huge amount of electrocardiogram (ECG) data for analysis, storage and transmission; an efficient ECG compression technique is needed to reduce the amount of data as much as possible while pre-serving the clinical significant signal for cardiac diagnosis, for analysis of ECG signal for various parameters such as heart rate, QRS-width, etc. An effective data compression scheme for ECG signal is required in many practical applications such as ECG data storage, ambulatory recording systems and ECG data transmission over telephone line or digital telecommunication network for telemedicine. EMD relies on a fully data-driven mechanism that does not require any priori known basis. It is suited for nonlinear and non-stationary signals, such as biomedical signals. Through a sifting process, the EMD can decompose the signal into a series of intrinsic mode function (IMFs). An IMF is defined as a function with equal number of extrema and zero crossings (or at most differed by one) with its envelopes, as defined by all the local maxima and minima, being symmetric with respect to zero. Basically IMFs represents the oscillatory modes of a signal. The lower order IMFs represents the fast or high frequency oscillations whereas upper order IMFs correspond to slow or low frequency oscillations. As per the characteristics of ECG, QRS complex is the high frequency component and P and T waves are the low frequency components of the signal. Hence lower order IMFs can be combined together to reconstruct the signal which highlights QRS region over the other waves and low frequency noises like baseline drift due to respiration etc [12].

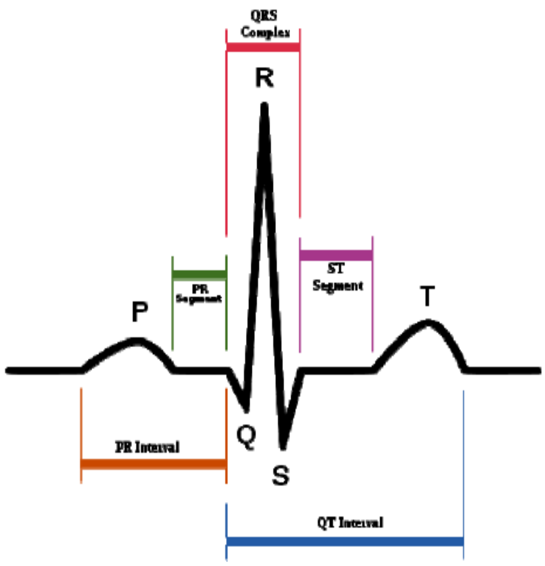

Figure 1. ECG signal and its features[2]

In general R wave is the highest amplitude and smallest duration wave in the ECG signal. Being the high frequency part of the mother wave, it must be represented by the lower order IMFs as discussed earlier. Earlier studies [10-11] shows that QRS region is better captured in first three IMFs. Any QRS detection algorithm involves many steps such as filtering, transformation and peak detection etc. So all algorithm can be categorized in three steps. These steps are

Preprocessing: In QRS detection first step is band pass filtering to remove baseline drift and high frequency component specially 50 or 60 Hz interference of electric power line. This is more important to separate R peak to other artifacts.

Transformation: To emphasis the QRS complex characteristics from the ECG signal we need transformation. Squaring, Averaging, Hilbert transform, Wavelet transform, Hilbert envelope (HE) is used as a transformation. These transform reduces the ambiguity in false detection and gives a large peak at the QRS complex compare to any other distortion.

Peak detection: Different methods applied on the transformed signal to peak detection. The transformed signal used as a input for different signal processing tools, and applied some decision rules to find real R-peak.

In EMD based algorithms these steps may be merged or can be performed separately. EMD decompose signal in to IMFs. So filtering also can be performed by EMD. Because, first three IMFs contain all information about QRS complex, therefore it is used to eliminate QRS complex from rest of signal. So EMD can perform half role of transformation.

II. ECG BEAT DETECTION FROM ECG PRINTOUT

This section is dedicated for ECG beat retrieval method from ECG printout[20].

A. *ECG paper scanning*

295 Hz (3.4 msecs/pixel) sampling rate for data recorded with speed of 25 mm/sec.

B. Select area of interest

An interesting ECG beat is then selected from the image for image and signal processing.

C. ECG image binarization

The selected segment of ECG image is loaded as gray scale because the color of ECG signal from the original paper is black and the color of paper grid is red. Threshold selection (130/255) is used for create binary image. But noise will appear in sometimes as shown figure 2. Then it needs to eliminate noise after binarizing the image.

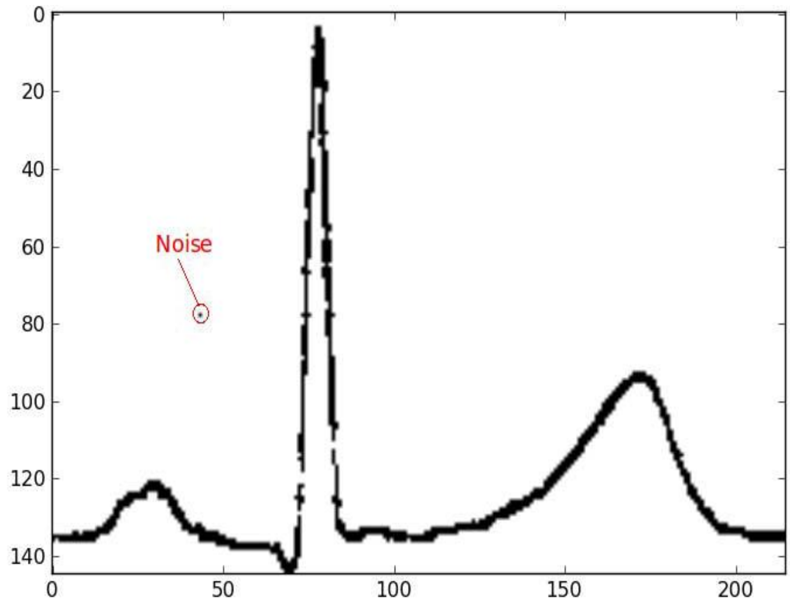

Figure 2. Binary image of ECG and noise[3]

D. Noise rejection

To remove the noise on the image after binarization process, the following process of noise rejection is applied to the binary image. The process starts by scanning vertically to find out the black pixel. If the black pixel is found and all adjacent pixels around it are white background color, then this black pixel will be considered and treated as a noise which will be replaced with white background color.

E. Image thinning

Since the line of ECG trace of original scanned image from ECG printout has a thickness which is a redundant of data in time series domain. Then thinning process with moving average algorithm is used to eliminate this redundant of data. Moving average in top-down fashion is used for thinning binary ECG images. When applying 5-point moving average to the binary image after noise rejection, the location of maximum value within 5-point window is used to determine the position of the thinning output pixel. This concept is illustrated in figure 3. The result of thinning process and noise rejection is shown in figure 4.

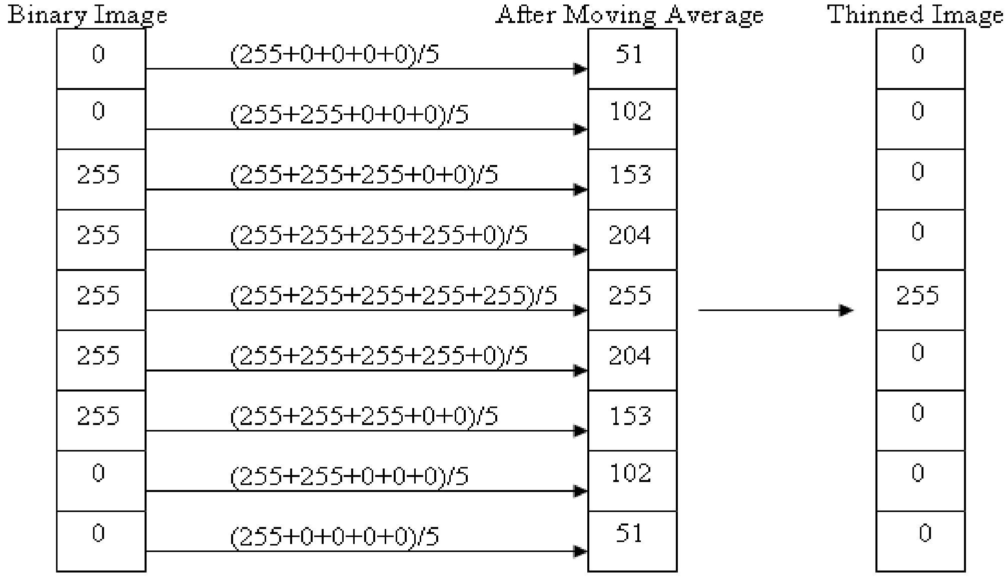

Figure 3. Concept of image thinning with moving average[6]

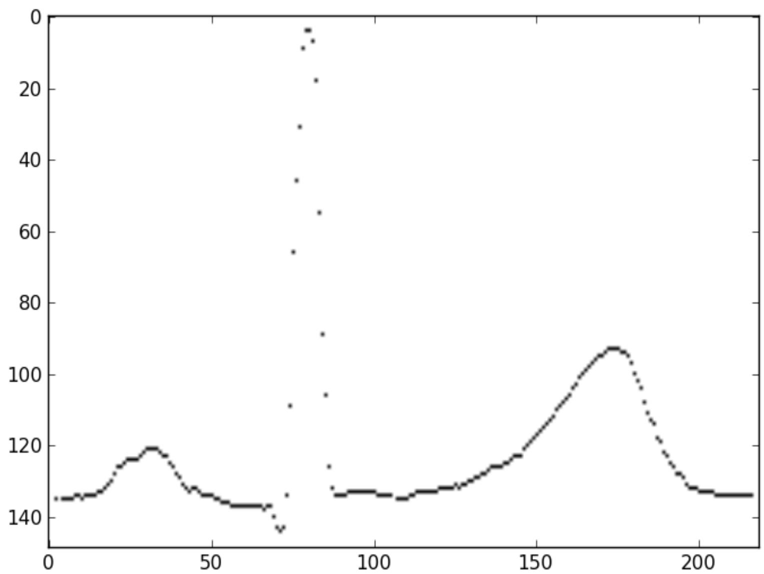

Figure 4. Output after thinning and noise rejection[4]

F. Time series data extraction

Time series data extraction is started from black pixel searching on each column with bottom-up style. After black pixel is found, its row index is used as the data value. This process is repeated on every column of image.

G. Time series data preprocessing

For classification ECG beat, the classifier use its shape for classify. Then data preprocessing is required. This preprocessing comprises of normalization and mean subtraction for generate zero-mean signal. The equation for normalization is shown in (1).

$$x[N] = x[N] - \min(x)/\max(x)-\min(x) \qquad (1)$$

H. QRS complex detection

After we create zero-mean normalized ECG signal. The absolute value of zero-mean normalized signal is used to find its envelope with Hilbert transform (green line on figure 5). The equation below is a Hilbert transform of real function $x(t)$ when $x(t)$ is ECG time series data.

$$H[x(t)] = \frac{1}{\pi}\int_{-\infty}^{\infty} x(\tau)\frac{1}{t-\tau}d\tau \qquad (2)$$

Finally the peak of QRS complex is located by looking for the top of its envelope. The result of QRS detection after plotting the peak location of the QRS complex together with zero-mean normalized data and the envelope of its absolute value is shown in figure 5.

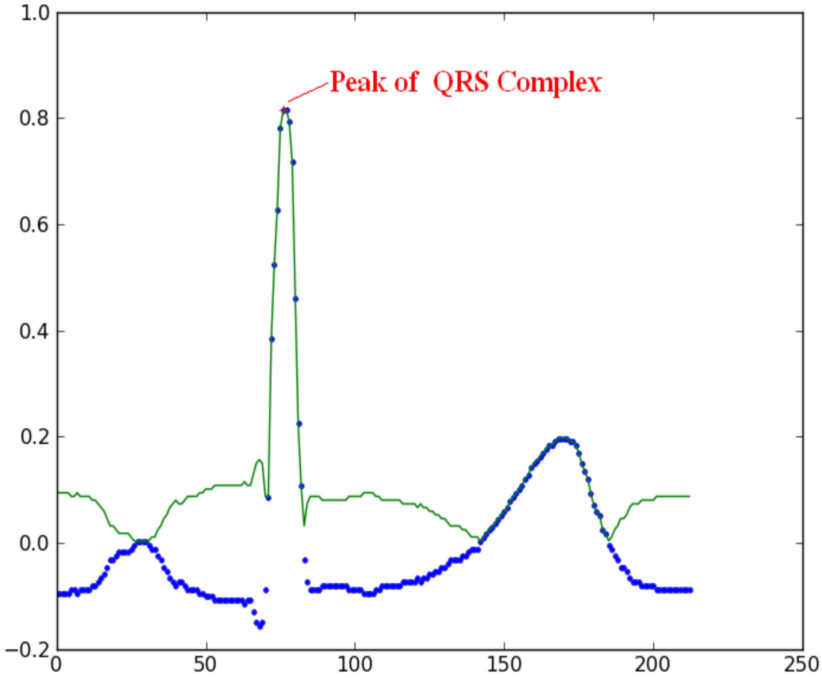

Figure 6. Output of QRS detection algorithm.

Blue-dots are time series data of ECG signal. Green line is the envelope of absolute value of zero-mean normalized data. A red-cross shows the location of QRS complex.

III. TYPES OF ARTIFACT IN ECG SIGNAL

The objectives of acquisition of ECG signal and signal processing system is to acquire the noise free signal. The major sources of noise are

1. Power line interference
2. Muscle contractions
3. Electrode contact noise
4. Motion Artifacts
5. Baseline wandering
6. Noise generated by electronic devices used in signal processing circuits
7. Electrical interference external to the subject and recording system
8. High-frequency noises in the ECG
9. Breath, lung, or bowel sounds contaminating the heart sounds (PCG).

There are various types of methods to extract the ECG parameters from the noisy ECG signal. First we need to analyze ECG signal to get which type of noise mesh up with the signal.

IV. ECG FILTERING

The filtering techniques are primarily used for preprocessing of the signal and have been implemented in a wide variety of systems for ECG analysis. Filtering of the ECG is contextual and should be performed only when the desired information remains ambiguous. Many researches have worked towards reduction of noise in ECG signal. Most types of interference that affect ECG signals may be removed by band pass filters; but the limitation with band pass filter is discouraging, as they do not give best result. At the same time, the filtering method depends on the type of noises in ECG signal. In some signals the noise level is very high and it is not possible to recognize it by single recording, it is important to gain a good understanding of the noise processes involved before one attempt to filter or preprocess a signal. The ECG signal is very sensitive in nature, and even if small noise mixed with original signal the characteristics of the signal changes. Data corrupted with noise must either filtered or discarded, filtering is important issue for design consideration of real time heart monitoring systems.[Himanshu, S. et al (2010)], designed amplifier using instrumentation amplifier AD620 (Analog Devices) to bring the peak value into a range of 1v; having gain of 1000. For collection of ECG signal he has used band pass filter with cutoff frequency 0.5Hz-150 Hz on NI ELVIS (National Instruments Educational Laboratory Virtual Instrumentation Suite) board.as shown in fig.

After the filtration the output of the analog filter is fed to the NI ELVIS[14] It has inbuilt data acquisition card. DAQ assistant is used to collect the signal after passing through the band pass filter. The data sampled at a rate of 1 KHz. After acquiring the signal it is processed by Butterworth (IIR) 3rd order digital filter. The first digital filter is band stop filter between 49.5 to 51.4Hz to eliminate power line interference. Butterworth filter having various orders, the lowest order being the best in time domain, and higher order being better in frequency domain. It is having monotonic amplitude frequency response, which is maximally flat at zero frequency response, and amplitude frequency decreases logarithmically by increasing frequency.

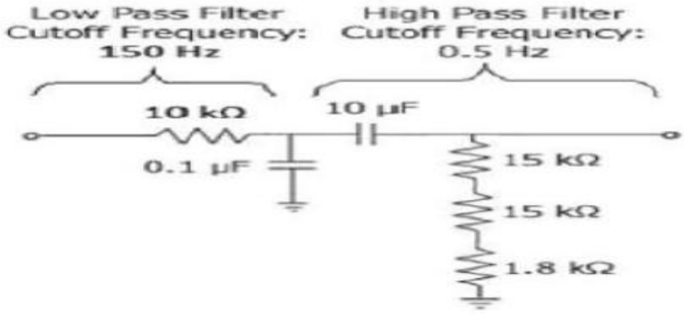

Figure 7. Band pass filter[10]

The main source of baseline wandering is respiration. It is having the frequency range between 0.15 to 3Hz. They used the wavelet transform to eliminate the Baseline wandering which is an effective way to remove the signal in specified sub-bands. After the removal of baseline wandering, the resulting ECG signal is more stationary and explicit than the original signal. For removing the wideband noises, using Wavelet Denoise Express VI, which is one of the tool of ASPT [10].Power line interference is due to improper grounding of ECG equipment and interference from near by equipment. It is removed by using notch filter. The power line interference is more influential on the signal compared to the other types of artifact [8]. The major source of such noise is electrical activity of the muscles that should be removed i.e. the noise present due to power line interface (50HZ) is also to be removed as shown in fig-3. Even though the analog amplifier having high Common Mode Rejection Ratio (CMRR), the ECG signals is contaminated by power line interference (50 HZ in India). In order to discard the sources of noise, proper filtration is required. The suppression of Baseline Wander and Power Interference can be done using digital IIR filter.

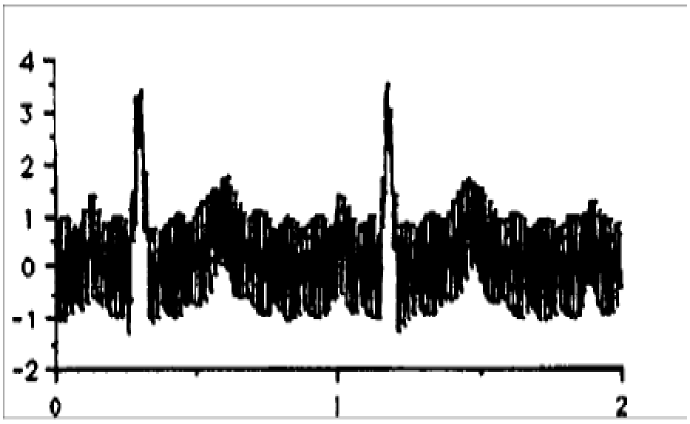

Figure.8- ECG corrupted due to power line interference[16]

Adaptive noise filtering is used for removal of 50 Hz that is the power line interference because, the ECG signal also contains 50 Hz signal and if normal band reject filter is used, then the 50 Hz signal which is very important in the ECG signal will be lost. Therefore by opting adaptive noise filtering, the power line frequency can be eliminated at the same time retaining the 50 Hz signal in the original waveform. Eduardo P. et al demonstrated in such a way that the signal from the ECG leads is applied to the inputs of an instrumentation amplifier scheme with a high common mode rejection ratio. The amplified signal is then filtered using a set of active filters in order to increase the SNR (Butterworth 50 mHz high-pass filter (HPF) to diminish baseline wandering and slow motion interferences and Butterworth 150Hz low-pass filter (LPF) to diminish the EMG interference .For 50Hz interference a 10th order notch digital filter was implemented as part of the digital signal processing. After analog filtering, the signal is acquired by a multifunction I/O board (NI USB-6008 with 12 bit resolution and 10 kS/s maximum sampling rate). The hardware is developed in order to create a portable system based on a Laptop where the data acquisition device (DAQ) is USB bus-powered and the ECG conditioning circuits are powered using two 9V (2500mAh) batteries incorporated in the system (the lifetime of the batteries is large, as the power consumption is only of 25 mA). The active high-pass filter removes the baseline fluctuations; the implemented digital filtering block consists of a 150 Hz Bessel LPF and the 50Hz notch filter in order to obtain a better SNR. After digital filtering the digital signal is processed using an ECG analysis block.

V. TYPICAL QRS DETECTION SYSTEM

QRS detectors, Arrhythmia monitors (recent commercial implementation of QRS detectors) and such similar manifestations, typically, include the following functional blocks:

1) Data acquisition
2) Signal conditioning.

3) Linear digital filtering
4) Non-linear transformation
5) Decision mechanism

Digital Filter Block is, essentially, a band pass filter that is, possibly, built as a cascade of a Low Pass Filter (LPF) and a High Pass Filter (HPF). The use of band pass filter improves the Signal-to-Noise (S/N) ratio and hence enables the use of lower thresholds thus leading to improved detection sensitivity.
Non Linear Transformation: is, essentially, implemented as a differentiator. Although this exercises an ideal attempt in detecting the QRS complexes, this functional block has its intrinsic impact owing to which there exists reasonable compromise on the width of the QRS complex and also its amplitude.
Squaring Process: intensifies the slope of the frequency response curve of the derivative and helps restrict false positives caused by T waves with higher than usual special energies. The output of the squaring block shall be passed through the decision making mechanism which, effectively, detect the QRS complexes. The decision mechanism, nominally, include a sets of thresholds to be applicable, mainly, based on the input signal strength, noise immunity (internal to the system or exterior to it), etc.

VI. METHODOLOGY

In this section three different QRS detection algorithms based on EMD are presented. These methods are recently presented. All three methods are used basic EMD techniques.

Method – I

In this method as the first several IMFs are mainly caused by the QRS complex and the high frequency noise, this indicates that denoising on the first several IMFs can filter out the noise and preserve the QRS content. In our method, the first three IMFs are treated with soft thresholds to eliminate high-frequency noise and then are summed together to yield a new signal d(t) . The new signal d(t) can be seen in Fig.3 and Fig. 4 for the clean ECG signal and the noisy signal respectively. The corresponding relationship between the modulus maxima of d(t) and the feature points of the QRS complex connected by the dash lines are also shown in the two figures. From the two figures, we can see clearly that the peaks of QRS correspond to the modulus maxima of d(t) and the QRS is bounded by two zero-crossing points. Such a discovery reminds us that the QRS complex can be easily detected with the modulus maxima method [6]. As most of the QRS are detected in d(t) in our algorithm, d(t) is named the detection layer. In case of false negative detection of the R wave, a leakage detection layer w(t) and a verification layer v(t) are constructed.
The detail QRS complex detection procedure can be as follows [1]:
1. Read the ECG signal and segment it in every 5 seconds length. Apply the EMD to each segment. Denoise the first three IMFs with the soft threshold method respectively and sum the denoised IMFs to obtain the detection layer d(t) . Sum the detection layer d(t) and the 4th
IMF to form the verification layer v(t);
2. The last two IMFs are given to zero and reconstruct the signal with the new IMFs, which forms the leakage detection layer w(t) .
3. With an adaptive amplitude threshold ε to detect all the modulus maxima point in the detection layer d(t).
The point meets the threshold condition can be considered as an R wave.
4. Calculate the average RR interval Trr in the current segment. If there is an RR interval in the current segment longer than 1.5* Trr, such an RR interval will be regarded as a leakage interval. Then half the threshold ε and detect the modulus maxima of the leakage interval in the detection layer d(t) again. If no QRS then switch to leakage layer. Find the maxima point using modified threshold. If detected maxima are not in range of 10-20 ms from the R point in detection layer, it will be consider as new QRS and repeat for three different modified threshold.
5. Utilizing the refractory period, if there is an RR interval shorter than the refractory period, the smaller amplitude of the R wave in w(t) will be treated as a false positive point and discarded.

VII. CONCLUSION

In this paper the preprocessed signal is transformed to get the decorrelated coefficients. Among the four techniques presented, DST provides lowest CR and distortion is also high. FFT improves CR and lowers PRD. So FFT is better choice than DST. Next is DCT which gives higher CR up to 91.68 with PRD as 0.8392. But DCT-II provides an improvement in terms of CR of 94.28 but PRD increases up to 1.5729. Thus an improvement of a discrete cosine transform (DCT) is presented as DCT-II. When we see the percentage of compression ratio DCT – II has fewer ratios of 20% which is very less than other techniques. The appropriate use of a block based DCT-II associated to a uniform scalar dead zone quantiser and arithmetic coding show very good results, confirming that the proposed strategy exhibits competitive performances compared with the most popular compressors used for ECG compression.

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