A STUDY ON OPTIMIZING ECG SIGNAL PROCESSING

NGHIÊN CỨU ÁP DỤNG MỘT SỐ THUẬT TOÁN TỐI ƯU QUÁ TRÌNH XỬ LÝ TÍN HIỆU ĐIỆN TIM

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ABSTRACT

Today the new biometric data such as electrocardiogram (ECG), electroencephalogram (EEG) is very interesting due to the demand for remote health monitoring. However the volume of ECG data produced by monitoring systems can be quite large, and data compression is needed for efficient transmission over mobile networks. The research investigated to compress ECG signals using JPEG2000. Also proposed is a method of ECG signal de-noising based on Hilbert-Huang transform. This method uses empirical mode decomposition to decompose the signal into several intrinsic mode functions (IMFs) and then the noisy IMFs are removed by using soft-threshold method. Experiments using the MIT-BIH arrhythmia database illustrate that the proposed approach has improved the performance at a high compression ratio and also achieve the desired effect of de-noising.

Keywords: *Electrocardiogram, ECG compression, signal de-nosing, Hilbert-Huang transform, empirical mode decomposition*

TÓM TẮT

Ngày nay các dữ liệu sinh trắc mới như tín hiệu điện tim (ECG), điện não (EEG) đang rất được quan tâm do nhu cầu về theo dõi sức khỏe từ xa. Tuy nhiên khối lượng các tín hiệu ECG được tạo ra bởi hệ thống giám sát là khá lớn nên việc nén dữ liệu rất cần thiết trong việc tăng hiệu quả truyền dẫn tín hiệu qua mạng di động. Nghiên cứu này đề xuất nén tín hiệu ECG bằng cách sử dụng giải thuật JPEG2000. Đồng thời sử dụng phương pháp biến đổi Hilbert-Huang để giảm nhiễu cho tín hiệu ECG. Phương pháp này sử dụng phân tích thực nghiệm để phân tích các tín hiệu thành các nội hàm (IMFs) và sau đó loại bỏ các thành phần nhiễu bằng phương pháp giảm nhiễu soft-threshold. Các thí nghiệm được thực hiện trên cơ sở dữ liệu về rối loạn nhịp tim của MIT-BIH và phương pháp đề nghị đã đạt được hiệu suất nén cao đồng thời đạt được hiệu quả giảm nhiễu như mong muốn.

Từ khóa: *Tín hiệu điện tim (ECG), nén tín hiệu ECG, giảm nhiễu tín hiệu, biến đổi Hilbert-Huang, phân tích thực nghiệm*

1. FUNDAMENTAL OF ECG SIGNALS

To provide personalized medical treatment continuously and remotely, physiological signals such as electrocardiography (ECG) are measured by sensor devices and transmitted wirelessly to the remote server for monitoring or analysis. A coding technique that provides channel efficiency is needed because it helps reduce resources usage, such as data storage space or transmission capacity.

ECG signals are very weak compared to the measurement noise, so that some analysis tools are needed for signal denoising. Hilbert-Huang Transform (HHT) is a powerful tool for signal analysis, due to its ability to extract periodic components which are embedded in a certain signal [1-3].

Most of the existing ECG compression methods adopt one-dimensional (1-D) representations for ECG signals. However, the ECG signals have both sample-to-sample (intra-beat) and beat-to-beat (inter-beat) correlation. Convert 1-D to 2-D representations through the combined use of QRS detection and period normalization [4,5].

The MIT-BIH Arrhythmia Database contains 48 half-hour excerpts of two-channel ambulatory ECG recordings, obtained from 47 subjects studied by the BIH Arrhythmia Laboratory between 1975 and 1979. Twenty-three recordings were chosen at random from a set of 4000 24-hour ambulatory ECG recordings collected from a mixed population of inpatients (about 60%) and outpatients (about 40%) at Boston's Beth Israel Hospital; the remaining 25 recordings were selected from the same set to include less common but clinically significant arrhythmias that would not be well-represented in a small random sample [6].

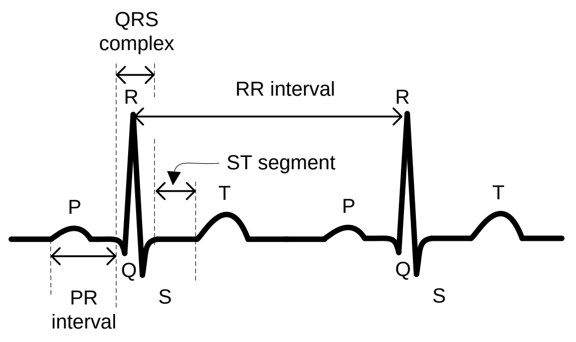


Figure 1. *Typical cardiac cycle*

2. HILBERT-HUANG TRANSFORM FOR ECG DENOISING

The HHT consists of two parts: empirical mode decomposition (EMD) followed by Hilbert spectral analysis (HAS).

2.1 Empirical mode decomposition (EMD)

EMD is the first step to deal with data from nonstationary and nonlinear processes. The decomposition is based on the simple assumption that any data is composed of different intrinsic modes functions (IMF).

The procedure of producing IMFs starts with finding local maximum and minimum of the signal.

The average value of the curve's maxima and minima is called m_1 with relation to $x(t)$ as:

$$x(t)-m_1(t)=h_1(t) \quad (1)$$

The first component h_1 is checked to see if it satisfies the above-mentioned two conditions. If not satisfied, we treat h_1 as original data and repeat the above process to obtain

$$h_1(t)-m_{11}(t)=h_{11}(t) \quad (2)$$

This calculation is repeated till h_{1k} is found out:

$$h_{1(k-1)}(t)-m_{1k}(t)=h_{1k}(t) \quad (3)$$

which satisfies the two conditions and is designed as the first IMF $c_1(t)=h_{1k}(t)$. It means c_1 should contain the shortest periodic component of the signal.

After taking c_1 out of the original data, we have the residue,

$$x(t)-c_1(t)=R_1(t) \quad (4)$$

Since the residue still contains the long-cycle variations in the data, it will be treated as the new data followed by the filtering process. This procedure is repeated with all R_i

$$R_1(t) - c_2(t) = R_2(t), ..., R_{n-1}(t) - c_n(t) = R_n(t) \quad (5)$$

The process can be stopped when $R_n(t)$ becomes so small that no more IMFs can be extracted or when R_n becomes a single function. By summing up the IMFs, the $x(t)$ can be represented by:

$$x(t) = \sum_{i=1}^{n} c_i(t) + R_n(t) \quad (6)$$

2.2 Hilbert Transform

Having obtained the IMF components, the Hilbert transform process is performed on every IMF to obtain a new time series $y_i(t)$ in the transform domain as follow

$$y_i(t) = \frac{1}{\pi} p \int \frac{c_i(t')}{t - t'} dt' \quad (7)$$

With this definition, a complex series $z_i(t)$ is formed in terms of

$$z_i(t) = c_i(t) + jy_i(t) = a_i(t) e_i^{j\theta(t)} \quad (8)$$

where the amplitude of $z_i(t)$ will be:

$$a_i(t) = \sqrt{c_i^2(t) + y_i^2(t)} \quad (9)$$

and phase

$$\theta_i(t) = \arctan\left(\frac{y_i(t)}{c_i(t)}\right) \quad (10)$$

Additionally, the instantaneous frequency is calculated by Eq. (11).

$$\omega_i(t) = \left(\frac{d\theta_i(t)}{dt}\right) \quad (11)$$

Unlike the FFT, $a_i(t)$ and $\omega_i(t)$ derived by HHT are functions of time t, so the HHT can characterize the variation of power with time.

2.3 HHT-based denoising

After EMD on the noisy signal are conducted, the energy of the IMFs is analyzed to separate the IMF components into signal-dominated parts and noise-dominated parts. By exploiting the fact that the scale of the IMFs components is dramatically increasing, the energy of IMFs of Gauusian white noise will reduce as the number of decomposition increases. With this approach, the denoising processing based on HHT will be performed by applying filtering on each IMF.

3. JPEG2000-BASED ECG SIGNAL COMPRESSION

The JPEG2000 standard is currently being developed in the specific area of still image encoding. JPEG2000 is not only intended to provide rate-distortion and subjective image quality performance superior to existing standards, but also to provide features and functionalities that current standards can either not address efficiently or in many cases cannot address at all. Some representative features of JPEG2000 are lossless and lossy compression, embedded lossy to lossless coding, progressive transmission by pixel accuracy and by resolution, robustness to the presence of bit-errors and region-of-interest coding [7-9]. The discrete transform is first applied on the source image data, and then the transform coefficients are then quantized and entropy coded. The decoder is in fact the reverse of the encoder.

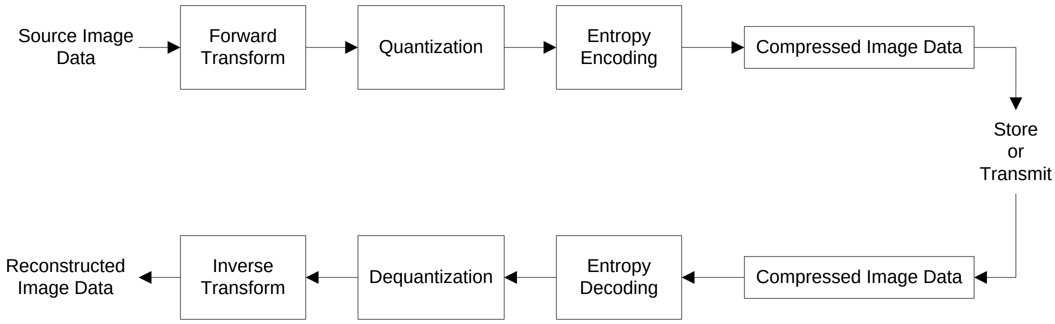


Figure 2.*The block diagrams of JPEG2000 codec*

The processing method of JPEG2000 is based on the standard of image tiles, ‘Tiling’. The term ‘tiling’ refers to the partition of the original (source) image into rectangular non overlapping blocks (tiles), which are compressed independently, as though they were entirely distinct images. All operations, including component mixing, wavelet transform, quantization and entropy coding are performed independently on the image tiles. In JPEG2000 encoding and decoding, the most important component of the standard is the specification of bit stream syntax, which is addressed comprehensively in the standard documentation. The core structure of the JPEG2000 encoder which is considered under the flow-of-bit view can be presented as a typical sequence as in Fig.3.

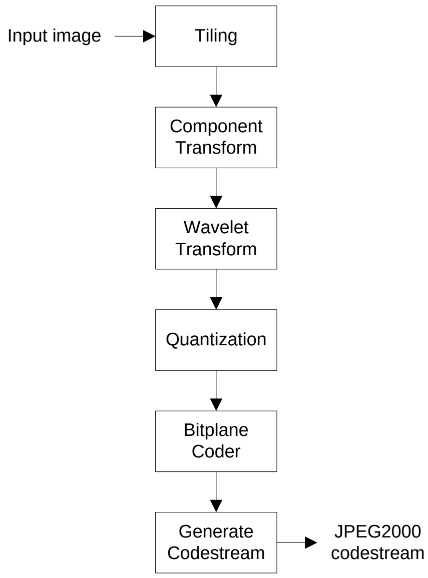


Figure 3. *Flow-of-bit view of JPEG2000 encoder*

The dependencies in ECG signals can be broadly classified into two types: The dependencies in a single ECG cycle and the dependencies across ECG cycles. These dependencies are sometimes referred to as intrabeat and interbeat dependencies, respectively. An efficient compression scheme needs to exploit both dependencies to achieve maximum data compression.

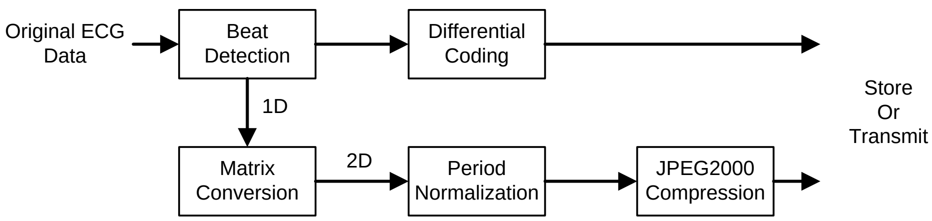


Figure 4.*Block diagram of ECG encoder using JPEG2000*

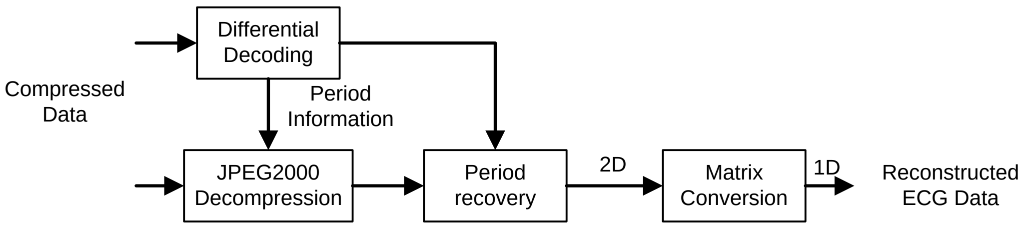
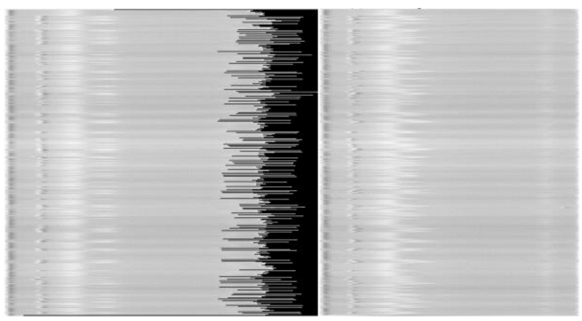


Figure 5. *Block diagram of a ECG decoder using JPEG2000*

To compress the ECG data through a JPEG2000 codec, the one-dimensional ECG sequence needs to be processed to produce a two-dimensional matrix. Since it is desirable to exploit both the intrabeat and interbeat dependencies, the segmentation of the ECG sequence should be performed in such a fashion that the resulting matrix allows exploitation of both types of dependencies by the JPEG2000 codec. The period-normalized matrix corresponding to the data in Fig6a is shown in Fig.6b.

Besides compression efficiency, the method benefits from desirable characteristics of the JPEG2000 codec, such as precise rate control and progressive quality.



(a) (b)

Figure 6. *(a) Before period normalization, (b) After period normalization*

4. EXPERIMENTAL RESULTS

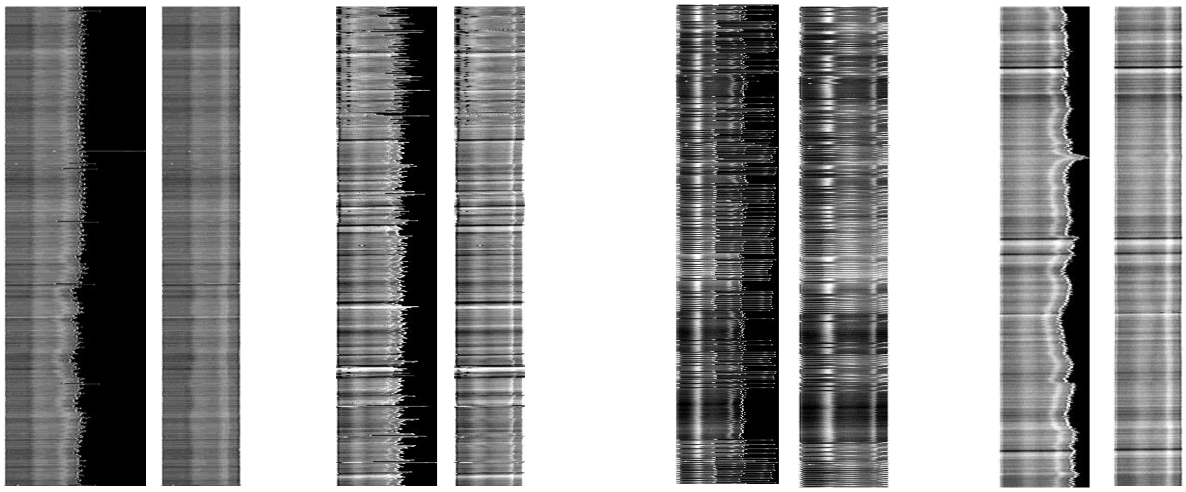
Algorithm represents the ECG compression based on JPEG2000. Also included is the application of HHT to ECG signal denoising. QRS complex detection and period normalization are applied for preprocessing.

We used four datasets formed by taking the four records (MIT-100, MIT-108, MIT-119, MIT-122) from the MIT-BIH arrhythmia database. The four datasets are individual 10 min of data from the four records. PRD was used to evaluate the error between the original and the reconstructed ECG signals. The reported CR are from actual compressed files and include all side information required by the decoder. Modification of the proposed scheme is to achieve lossless decompression by utilizing the lossless compression capability of JPEG2000.

Table 1. *Performance results of Algorithm II*

ECG sources	PRD(%)	CR
MIT-100	3.0523	13.9534
MIT-108	6.4794	18.8851
MIT-119	2.6751	16.0050
MIT-122	1.6115	12.7506

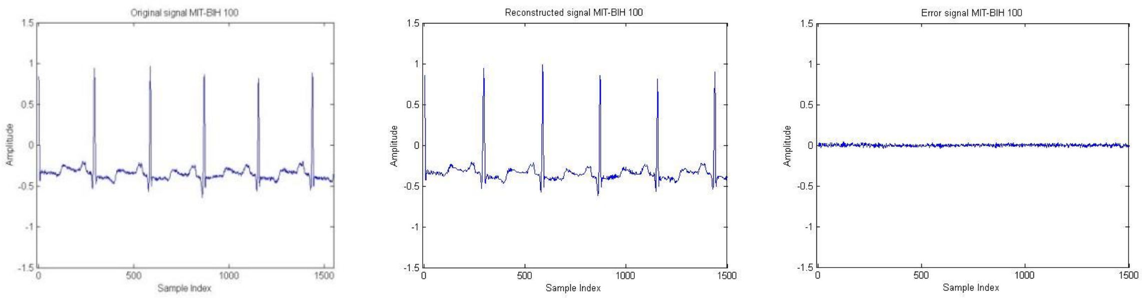
The differences of the 4 records are of the existence of different interferes from the environment, sensors and the diseases of patients. The sources interfere by high frequency noise and ones with lower affection of the environment showed different results in PRD.



(a) (b) (a) (b) (a) (b) (a) (b)

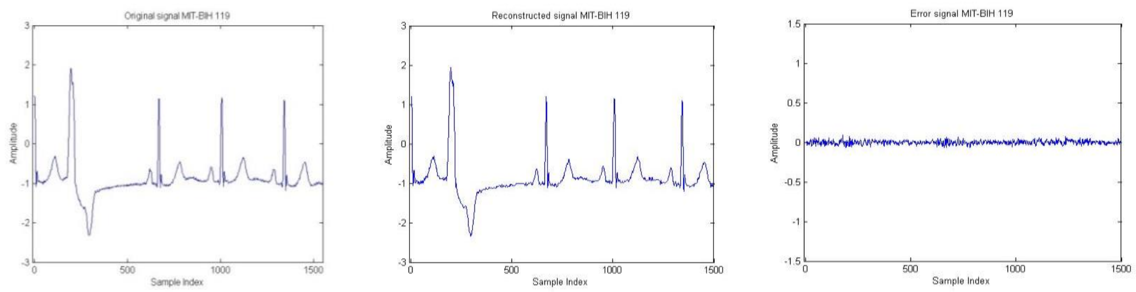
MIT-100 MIT-108 MIT-119 MIT-122

Figure 7. *(a) Original matrixes, (b) After period-normalization matrixes*



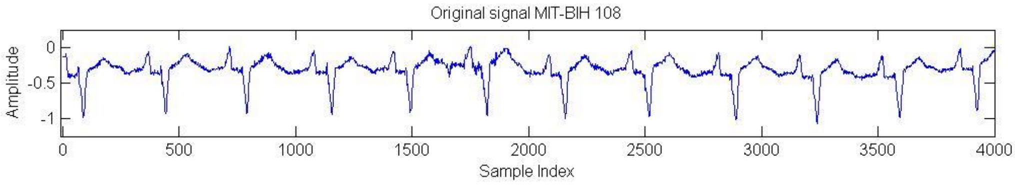
(a) (b) (c)

Figure 8.*Results of Algorithm in MIT-BIH 100:(a) Original signal, (b) Reconstructed ECG waveforms, and (c) Error signals*

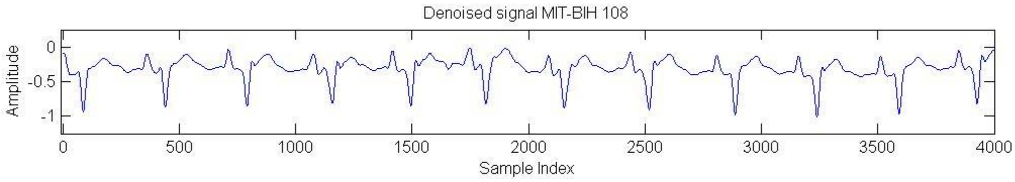


(a) (b) (c)

Figure 9.*Results of Algorithm in MIT-BIH 119: (a) Original signal, (b) Reconstructed ECG waveforms, and (c) Error signals*



(a)



(b)

Figure 10. *MIT-BIH 108: (a) Original signal,(b)Denoised signal*

Table 1 shows the differences among the four records due to the difference of the interbeat and intrabeat correlations. Consequently, PRD obtained by MIT-BIH 108 significantly higher than MIT-BIH 122 when the signal have the correlations of the beat-to-beat.By comparison to beat-based ECG compressing using GSVQ [10], the proposed scheme gives a difference in details of the application of VQ algorithm in several channels.

5. CONCLUSIONS

The results show that the HHT method can remain more valuable details of signal, because it can make prevention of energy leak and the energy is more centralized in spectrum.

HHT can be used to analyze nonstationary signal and thus achieve the desired effect of de-noising. The EMD is adaptive, since the basic functions extracted from original data are based on residue of the last filtering, which are alterable in HHT.

HHT method can be used to analyze the biometric signals such as electro-encephalogram, face recognition, fingerprint and voice.

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