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Survey on the methods of Electrocardiogram Signal Compression

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ABSTRACT: *A broad spectrum of techniques for electrocardiogram data compression has been proposed during the last three decades. Compression techniques are essential to wide variety of application ranging from diagnostic to ambulatory ECG. An ECG contains diagnostic information related to cardiac activity. A method to compress diagnostic information without losing data is required to store and transmit them efficiently on a wireless personal area network (WPAN). As electrocardiogram (ECG) signals are generally sampled with a frequency of over 200 Hz, an ECG signal compression method for communications on WPAN, which uses feature points based on curvature, is proposed. The feature points of P, Q, R, S, and T waves, which are critical components of the ECG signal, have large curvature values compared to other vertexes. Thus, these vertexes were extracted with the proposed method, which uses local extrema of curvatures. Furthermore, in order to minimize reconstruction errors of the ECG signal, extra vertexes were added according to the iterative vertex selection method. It was concluded that the vertexes selected by the proposed method preserved all feature points of the ECG signals. In addition, it was more efficient than the amplitude zone time epoch coding method.*

Keywords: *Electrocardiogram (ECG), Curvature, Feature Extraction, Vertex*

I. INTRODUCTION

The continuing proliferation of computerized ECG processing system along with the increased feature performance requirements & demand for lower cost medical care have mandated reliable , accurate & more efficient ECG data compression techniques. Electrocardiogram (ECG) represents cardiac electrical activity by a graph that contains pre-diagnosis information of various cardiac diseases. ECG signal measures very large amounts of data in a short period of time, because it typically has a higher than 200 Hz sampling frequency. Extensive ECG signal data is not suitable for wireless personal area networks (WPAN), because healthcare monitoring system requires a real-time process [1] – [5]. In order to telecommunicate the extensive ECG signal on WPAN, it is needed to compress the signal without loss of significant information for diagnosis. However, compression distortion is able to cause misdiagnosis of healthcare monitoring system. Therefore, the main features of the diagnostic value should be maintained within the tolerance range. Conventional ECG compression research contains the direct compression method, transformational compression method and so on.

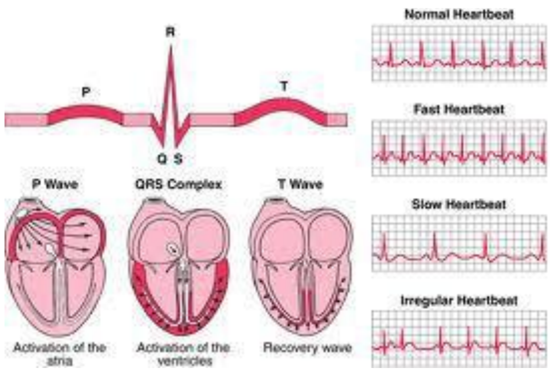

Fig.1 Typical ECG Signal

In order to delineate the accurate description of ECG signal, a variety of approaches, such as those based on numerical differentiation, pattern recognition, and mathematical models have been proposed. The direct compression method detects the redundancy of an ECG signal and eliminates it in the time-domain. This approach contains a turning point (TP) [6], amplitude-zone-time epoch coding (AZTEC) [7]; coordinate reduction time encoding system (CORTES) [8], differential pulse code modulation (DPCM) [9], and etc. The conversion compression method is based on spectrum analysis and energy distribution analysis, which provide the detection of redundancy. Fourier transform, Walsh transformation, wavelet transform, and Karhunen-Loeve transform are conventional conversion compression methods [10]–[12]. The conventional ECG compression method is able to generate distortion of important ECGcomponents, such as P, Q, R, S, and T waves [13], [14]. On the other hand, this paper proposes a P, Q, R, S, and T wave preserving compression method based on local extrema of curvature. Also, the proposed method supplements the vertexes using the iterative refinement method (IRM) to improve peak signal to noise ratio (PSNR) in the compressed ECG signal. Experimental results using the Massachusetts Institute of Technology-Beth Israel hospital (MIT-BIH) arrhythmia database verify the superiority of proposed method.

This paper is described by the following contents. The proposed method, which is based on curvature, is explained in Section 2. Then, section 3 makes the conclusion of this paper.

II. COMPRESSION OF ECG SIGNAL BASED ON CURVATURE

A typical ECG signal has a P wave, QRS-complex, and T wave, all of which are important component of a diagnosis (Fig. 1). The start and end points of P, Q, R, S, and T waves are important feature points for diagnosis of heart disease. These feature points have a larger signal variation rate than other regions. Therefore, the proposed method selects the vertex, which has a larger curvature value than the threshold value. However, because selected vertexes are unable to reflect detail components of an original ECG signal, we required to supplement the vertexes using the IRM. The practical importance of ECG data compression has become evident in many aspects of computerized electrocardiography including: a) Increased storage capacity of ECG as databases for subsequent comparison or evaluation, b) feasibility of transmitting real time ECG over the public phone network, c) implementation cost effective real time rhythm algorithms, d) economical rapid transmission of off-line ECG over public phone lines to a remote interpretation center and e) improved functionality of ambulatory ECG monitors and recorders. Median filter is used to calculate the average value of ECG signal.

2.1Vertex Selection Based on Curvature

The proposed method calculates the curvature value of the input ECG signal for vertex selection. Curvature refers to the deviation rate of a curve or the curved surface from a straightline or plane surface tangent to it [15]. Curve function based on a time variable *t* is represented as

$$O(t) = (S(t),V(t)) \quad (1)$$

Where *s*(*t*) is a sample index at *t* and *v*(*t*) is a signal voltage. A typical ECG signal contains 50 Hz power line noise, baseline wander, muscle noise, and so on. Therefore, an accurate ECG compression we get after performing following algorithm.

$$C(t,\sigma) = (S(t, \sigma), V (t, \sigma)) \quad (2)$$

Where $$S(t, \sigma) = S(t) \otimes g(t, \sigma) \quad (3)$$

And $$g(t,\sigma) = 1/(2\pi)^{\wedge}1/2\exp(-t^{\wedge}2/2\sigma^{\wedge}2) \quad (4)$$

where g(t, σ) is a Gaussian function for smoothing with the standard deviation σ. Curvature k(t, σ) based on smoothed signal
k (t, σ) is calculated by

$$k(t,\sigma) = \frac{S''(t,\sigma)V'(t,\sigma) - S'(t,\sigma)V''(t,\sigma)}{\{S'(t,\sigma)^2 + V'(t,\sigma)^2\}^{\frac{3}{2}}} \quad (5)$$

The selection process of vertexes consists of the following five steps:
Step 1: The original ECG signal is pre-processed by median filter.
Step 2: A Gaussian LPF is used to eliminate the high frequency noise in pre-processed ECG signal. The larger standard deviation σ is adopted, and a smoother signal is generated. The smaller σ causes over-detection of local extrema*k*loe.
Step 3: R wave is detected by local extrema*k*loe, which is located at the maximum voltage.
Step 4: Curvature is calculated at all of vertexes.
Step 5: Final vertex is selected by curvature value threshold. After performing above steps the noise eliminated ECG signal *C* (*t*). Vertexes are, marked as „O" and „X" are the top five points of local maxima, and the bottom six points of local minima, respectively Then we restored ECG signal based on selected vertexes. However, the restored ECG signal is needed to supplement vertexes because it has over-distortion with the original ECG signal.

2.2 Supplemental Vertex Selection

The initial points for vertex supplement are two adjacent vertexes. Supplemental vertexes are selected at the point which is larger than *D*MAX, where *d* means the vertical distance between the initial point"s line and vertex.

$$T=(t1,t2, t3\ldots tc\ldots tn) \quad (6)$$

Where *tx* is the time axis and *N* is the number of the axis between A and B. The voltage of the vertexes is determined by

$$V=(v1,v2,v3\ldots vc\ldots vtn) \quad (7)$$

Step 1: Initial vertexes with larger curvature are selected.
Step 2: Select the distance value *dm* between the initial vertexes A and B.
Step 3: Supplemental vertexes are selected by the condition of *d*max>*D*th
Step 4: Selected supplemental vertexes are connected to the initial vertexes as a line for the restored signal. *Rsp*is the restored signal that used not only the initial vertexes but also the supplemental vertexes.

In above process, *D*th is set by the condition of that percent of root mean square difference is under 9% [17]. And by the experimental result, in the case of *D*th is 0.017, the condition is satisfied. Thus, the higher *D*th is set, the larger error rate of the restored signal is recorded.
The important components of the ECG signal such as P, Q, R, S, and T waves and P-start, P-end, QRS-start, QRS-end, T-start, and T-end points are preserved effectively.
The above methodology for compressing ECG signals in automatic way guaranteeing signal interpretation quality. The approach is based on noise estimation in the ECG that is used as compression threshold in coding stage.

The compressed points rte (CPR) is used for measurement of compression rate and restore error. CPR based on the number of vertexes is expressed as

$$CPR = \frac{Lc(t)}{Lr(t)} \quad (8)$$

Where Lc(t) and Lr(t) are the number of vertexes in the preprocessed and compressed ECG signal, respectively.

III. CONCLUSION

The ECG signal has important components for diagnosis, such as P wave, QRS-complex, and S wave. First, the proposed method selects the vertexes based on curvature value. However, selected vertexes are not suitable to minimize the restore error. Therefore, supplemental vertexes are selected by the IRM. Through the experimental results, the proposed method provides both a higher compression performance and less distortion of the restored signal than AZTEC. The proposed method is able to improve the effectiveness of telecommunication in WPAN because of its robust compression performance.

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