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2-D ECG Compression Using Optimal Sorting and Mean Normalization

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Abstract. In this paper, we propose an effective compression method for electrocardiogram (ECG) signals. 1-D ECG signals are reconstructed to 2-D ECG data by period and complexity sorting schemes with image compression techniques to increase inter and intra-beat correlation. The proposed method added block division and mean period normalization techniques on top of conventional 2-D data ECG compression methods. JPEG 2000 is chosen for compression of 2-D ECG data. Standard MIT BIH arrhythmia database is used for evaluation and experiment. The results show that the proposed method outperforms compared to the most recent literature especially in case of high compression rate.

Keywords: Electrocardiogram compression, Period sorting, Mean normalization, 2-D correlation.

1. Introduction

Variety of ECG compression methods has been proposed with satisfactory performance [1-9]. Most of the methods use 1-D representation for ECG signals such as long term prediction, vector quantization (VQ) or wavelet transforms [7-9]. However, many 1-D methods do not fully utilize inter beat correlation. It has been attempted to transform 1-D ECG signal into 2-D ECG data to get the most of benefit from both inter and intra-beat correlation [1-6]. The basic idea of 2-D ECG signal compression is that we want to treat ECG signals as the same way we treat an ordinary digital image in the conventional image compression methods. Lee and Buckley constructed 2-D ECG and applied DCT transform to that, Bilgin et al. applied JPEG2000, Tai et al. applied SPIHT algorithm and their works have achieved better results than 1-D compression methods [4-6]. These methods can be generally divided into three steps: QRS complex detection for segmentation of the ECG into periods, pre-processing, and transformation. The pre-processing step is the main focus of this paper. Several authors have successfully used period normalization [1, 3-4], which has led to significant improvements. However, there are factors that prevent the normalized periods from having high correlations, which may compromise the performance of the compressor. Also their compression performance dropped in cases of irregular ECG signals mainly because they cannot reduce high frequency redundancies among adjacent beats. Beat segment sorting methods are proposed such as period and complexity sorting schemes [1,2]. Period sorting reorders beat segments based on the length of each segment. Complexity sorting uses MSE (Mean Square Error) to sort beat segments. These 2-D ECG compression methods with sorting schemes have been reported to perform better than conventional 2-D ECG compression methods [1,2]. But weaknesses still remain such as increase of data size to encode, efficiency of sorting and so forth. The details of main weaknesses of them will be discussed in Section 2.In this paper, we propose an effective compression method to overcome the weaknesses of the conventional 2-D ECG compression methods. In the proposed method, constructed 2-D ECG data is segmented into groups and blocks to take full advantage of both complexity and period sorting schemes. It not only reduces size of image to encode and

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but also increases correlation between adjacent beat segments. The paper is organized as follows. Section 2 describes conventional 2-D ECG compression methods with sorting schemes and their drawbacks. Section 3 explains our proposed method. Section 4 demonstrates experimental results and analysis. Finally Section 5 summarizes and concludes this paper.

2. Conventional ECG Compression Methods

2.1. Conventional 2-D ECG Compression Methods

2-D ECG data is regarded as a normal image in 2-D ECG compression methods. Original 1-D ECG signals are transformed into 2-D ECG data representation. The transformation process is depicted in fig. 1. The transformed 2-D ECG signal is regarded as a normal image and it follows the same procedure as we compress a digital image. The conventional 2-D ECG compression process is illustrated in fig. 2.

2.2. Weaknesses of Sorting Based ECG Segment Methods

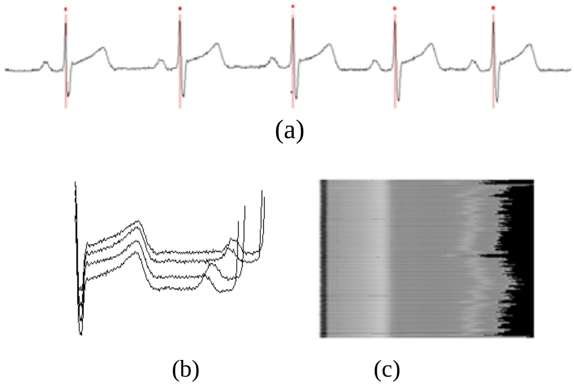


Fig. 1. 1-D ECG signals turn into 2-D ECG data, (a) 1-D ECG signals, (b) concatenation and (c) 2-D representation.

In spite of their high performance, the conventional ECG segment sorting based ECG compression methods have some weaknesses. Firstly, high frequency redundancies among adjacent beats still remain. DC

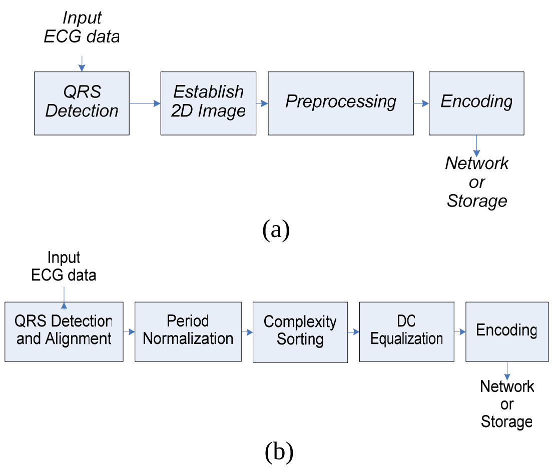


Fig. 2. Conventional ECG segment sorting methods (a) period sorting and (b) complexity sorting.

equalization reduces high frequencies effectively among adjacent beats. However there still exists the difference between adjacent beats originated from low frequency fluctuation or heart abnormalities. Secondly, misalignment of QRS complex position may occur due to period sorting. This phenomenon negatively affects the performance of overall compression process which can be demonstrated from a simple experiment with a couple of black and white image. The third weakness of the conventional 2-D ECG method is that normal and abnormal beats can be mixed together after period sorting when the length of the beats is similar to each other. In this case, we lose redundancy of inter-beat correlation. Finally, period normalization generally increases the size of image for compression especially when we normalize the beats based on the longest beat. This obviously degrades the overall performance of the compression

3. Proposed Method

3.1. QRS Complex Detection and Alignment

QRS complex detection is necessary for beat based compression scheme. We propose an appropriate scheme for decision on stating position. In this method, each QRS peak position of each segment is placed

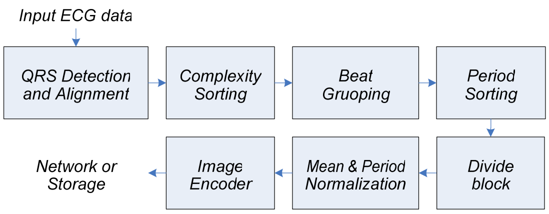


Fig. 3. Block diagram of the proposed method.

and aligned properly.

3.2. Complexity Sorting, Beat Grouping and Period Sorting

The sorting index is chosen by complexity sorting methods and the beats rearranged based on the sorting index. After complexity sorting beat segments with similar shapes are grouped. In this step we decide on the boundary of each group using image processing techniques such as median filter or Sobel operation [9]. Beat grouping algorithm can be described as follows: period normalization, noise reduction, edge detection, boundary decision. Period normalization uses B-spline interpolation to make length of each beat segment same. Median filtering is used for noise reduction and Sobel operation for edge detection. Inter-beat correlation can be increased in each group. The result of complexity sorting has irregular length which contains high frequency redundancy at the end of each segment. We solve this problem by applying period sorting technique to each group.

3.3. Division of Blocks

Each group is divided into three blocks. First block consists of the first k number of samples before QRS peak is positioned. Second block indicates middle position. The third block starts at the last sample of the shortest beat segment in the group.

3.4. Period Normalization and Block Based Normalization

There exist blocks filled with dummy data due to different length of period. Each horizontal line of those blocks is expanded using B-spline interpolation. Adjacent lines may have different DC levels which results in high frequency components along the vertical direction of the resulting image and it decreases the efficiency of a compression system. Conventional mean normalization scheme improves this problem to some extent but there is still more room for enhancement. In order for further improvement, we devised block based mean normalization procedure.

3.5. JPEG2000 Encoding

Each group is encoded using JPEG 2000 compression scheme for the purpose of suppression of high frequency around boundary area between groups for better compression performance. The Proposed 2-D ECG compression process is illustrated in fig. 3 and fig. 4 shows an example of process of the proposed method.

4. Experimental Results

4.1. Performance Criteria

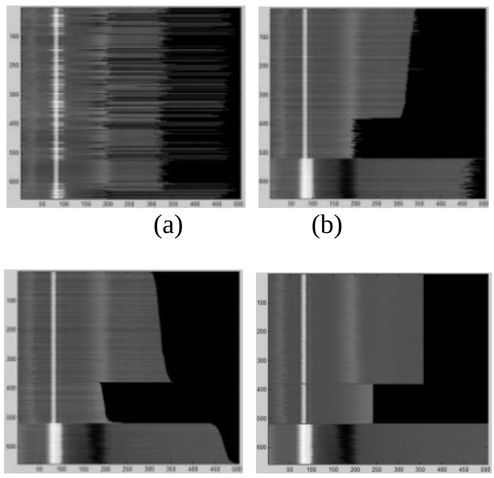
Two measurements are introduced for comparing performances of the proposed methods to other competitive algorithms: CR (Compression Ratio) and PRD (Percent Root mean squared Difference). The CR is calculated as the number of bits in the original 1-D ECG signal divided by the total number of bits in the compressed data.

$$CR = \frac{\text{The number of bits in the original 1-D ECG signal}}{\text{The total number of bits in the compressed data}} \quad (1)$$

The PRD can be calculated by normalized root mean squared difference between the compressed and original ECG sequences.

$$PRD = \sqrt{\frac{\sum_{i=1}^{L}\left(x_{org}(i) - x_{rec}(i)\right)^2}{\sum_{i=1}^{L} x_{org}(i)^2}} \times 100\% \quad (2)$$

where $x_{org}(i)$ is original ECG signal, $x_{rec}(i)$ is compressed and reconstructed signal and L is size of signal.



(a) (b)

(c) (d)

Fig. 4. Example of proposed method, (a) constructed 2-D ECG image, (b) image after complex sorting, (c) image after period sorting by groups, (d) image after period normalization and block based mean equalization.

4.2. Experimental Results

For evaluation of coding efficiency of the proposed method, we conducted experiments with the first 216, 000 samples from records 100, 117, and 119 in the MIT BIH ECG database. The signals are sampled at 360 Hz with 11-bit of sampling resolution. The dimensions of the resulting ECG images are variable and depend on the number of detected periods and their average length. The original length of each period, mean values and signal ordering are arithmetically encoded and sent to the decoder as side information. Table. 1 shows the proposed method shows higher performance than the methods recently reported methods in terms of compression ratio and reconstruction error.

5. Conclusion

In this paper, we propose an effective 2-D based ECG compression method. 1-D ECG signal is reconstructed to 2-D data using complex and period sorting schemes to increase inter and intra-beat correlation. 2-D data are divided into groups and blocks followed by mean normalization. JPEG2000 is chosen as a codec scheme. The proposed method reduces extra high frequency redundancy between adjacent beat segments for more efficient 2-D ECG data. Proposed method generates extra data called side information such as sorting, block, mean information and so on. In spite of the increase of side information, the proposed method outperforms the methods described in the literature especially in case of high compression rate. Future work will include further investigation on compression of side information which may add more compression power on top of the proposed method.

Table 1. Performance comparison on different ECG compression schemes to the proposed method.

Algorithm	Record	CR	PRD
Lee et. al[6]	100	24:1	8.10
Chou et. Al app. 2[2]	100	24:1	4.06
Filho et. al.[1]	100	24:1	3.95
Proposed	**100**	**24:1**	**3.53**
Filho et. al.	100	10:1	2.12
Proposed	**100**	**10:1**	**2.12**
Filho et. al.	117	24:1	1.72
Propsed	**117**	**24:1**	**1.64**
Chou et. Al app. 2	117	13:1	1.18
Filho et. al.	117	13:1	1.07
Proposed	**117**	**13:1**	**1.06**
Bilgin et. al[4]	117	10:1	1.03
Chou et. Al app. 2	117	10:1	0.98
Filho et. al.	117	10:1	0.86

Algorithm	Record	CR	PRD
Proposed	**117**	**10:1**	**0.85**
Bilgin et. al	117	8:1	0.86
Filho et. al.	117	8:1	0.75
proposed	**117**	**8:1**	**0.73**
Bilgin et. al	119	21.6:1	3.76
Tai[3]	119	20:1	2.17
Chou et. Al app. 2	119	20.9:1	1.81
Filho et. al.	119	20.9:1	1.92
proposed	**119**	**20.9:1**	**1.80**
Chou et. Al app. 2	119	10:1	1.03
Filho et. al.	119	10:1	0.93
Proposed	**119**	**10:1**	**0.92**
Filho et. al.	119	8:1	0.74
proposed	**119**	**8:1**	**0.73**

6. Acknowledgements

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