Two-Dimensional Compression of ECG Signals Using HEVC-Intra Encoder and Pre-processing Techniques

D. B. Gusmão, A. T. M. Lima, and M. V. C. Costa

Abstract

The paper presents the proposal of an electrocardiogram (ECG) compressor based on two-dimensional coding. The signal is pre-processed and the R waves detected, from these waves the signal is segmented and arranged in an $N \times M$ matrix, composed of M segments and N the maximum length between two R waves. Once this matrix is composed, the interpolation process is performed so that all segments M have the same size N. With the interpolated matrix a pre-processing is applied to improve the two-dimensional correlation of the matrix. This is done by rearranging the segments so that the correlation of the segments be maximized. Some widely-adopted image compression algorithm is used to reduce the volume of data. In the present work, the intra mode of the High Efficiency Video Coding (HEVC) is applied to encode real ECG signals obtained through the MIT-BIH Arrhythmia Database. These signals impose a greater challenge for the proposed system. The application of this proposal demonstrates that the use of HEVC-intra image encoder is efficient in ECG compression. A quantitative performance evaluation was performed and compared to other results found in the literature.

Keywords

Electrocardiogram • Data compression • HEVC-intra

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1 Introduction

The electrocardiogram (ECG) is a very powerful tool for medical diagnostics. The ECG is an electrical signal acquired on the surface of the skin in order to measure the functioning of the heart.

Over the years, the need for storage (or transmission) of these signals for future (or remote) analysis has arisen, as is the case of many portable devices [1]. In exams like the Holter monitor, the electrocardiogram is acquired during a long period of time. Due to the fact that the exam lasts 24 h, the device must have a reasonable amount of memory to store the information.

There are some works performed in ECG compression such as Lee et al. [2], in which the signal is segmented and aligned by the peak of the R wave so that compression is performed by the two-dimensional discrete cosine transform (DCT-2D). Bilgin et al. [3] uses the technique of segmentation by detection of the peak of R wave and the interpolation for the maximum length and the JPEG2000 is used for encoding. Tai et al. [4] uses a 1D wavelet-based technique (SPIHT), with several window sizes in order to find the best result.

Chou et al. [5] uses the reorder technique by increasing sample size and interpolation for maximum size and encoding through JPEG2000. Filho et al. [6] works with the equalization technique of dc value and rearrangement by complexity of each segment and encodes through JPEG2000 and H.264-intra. Joo et al. [7] applies standardized grouping techniques to improve the encoding through JPEG2000. Polania et al. [8] uses a compression-sensing technique with sub-Nyquist sampling for wavelet-based compression. Singh et al. [9] use the compressive-sensing technique for multi-channel electrocardiogram signals with wavelet transforms. Raeiatibanadkooki et al. [10] uses the wavelet transform in addition to the Chaotic Huffman encoder. Craven et al. [11] uses a compression-sensing technique with sub-Nyquist

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sampling with wavelet-based compression (SPIHT and EZW) and coding using adaptive dictionary.

The purpose of this work is to use pre-processing techniques consolidated in the literature and take advantage of the intra mode of High Efficiency Video Coding (HEVC), which performs as an image encoder. The HEVC is a state-of-the art encoder [12] and, to the best of our knowledge, was not tested before for the compression of biological signals. These signals are pre-processed to meet the requirements of the encoder, looking for an appropriate signal form that facilitates the compressor work and improves the quality of the compression.

2 Materials and Methods

For processing, ECG signals were used from physionet.org from the MIT-BIH Arrhythmia Database [13]. This database has been used in a number of articles on ECG compression. The main signals used were the 100, 117 and 119, always using the first 216,000 samples of each signal [6]. The MIT-BIH Arrhythmia Database signals has a resolution of 11 bits and 360 Hz sampling rate [13].

The encoding is actually performed by the HEVC acting in intra-frame mode. The HEVC-intra standard has two different prediction methods. The first method is the angular method, which is used to model structures with directional edges accurately. For this model, 33 different angles are used to construct the estimates [14]. The second method is the planar and DC, which estimates the soft components of the image [14]. With these two methods all forms of intra prediction add up to 35. All modes of intra prediction are based on previously predicted blocks. Prediction blocks would have sizes ranging from 4×4 pixels to 32×32 pixels.

All prediction modes are available for any block size. To improve the probability of finding a good prediction, the HEVC standard supports different preprocessing filters that are applied in the current prediction block in order to improve prediction efficiency [14].

The algorithm presented in this work consist of five sequential steps: R-wave peak detection, ECG segmentation, interpolation, correlation sorting and compression.

2.1 R-wave Peak Detection

For the detection of the R peaks, the algorithm described in Pan and Tompkins [15] was used. In this algorithm first step, the samples are filtered in order to reduce influence of noise in signal and the wander baseline. The second step is the signal differentiation, to provide QRS feature. On the next step, each signal sample is squared, to emphasize the high frequency content. The signal is then integrated by a moving window in the fourth step, to obtain waveform features. Then final step consists in apply a threshold to find where the QRS occurs.

This method was applied to find the difference between two consecutive R-peaks on the next step in this article.

2.2 ECG Segmentation

The segmentation process is responsible for transforming the ECG signal (which is one-dimensional) into a two-dimensional signal matrix. From the positions of the R peaks, the original signal was cut out and each segment between two R peaks was positioned in a line of the matrix.

The two-dimensional signal, considered as an image, has dimensions of length $\times$ segments of the largest segment. The example shown in Fig. 1 is the result of this process for the signal 119, based on the values generated in the R peak detector.

2.3 Interpolation

To improve the smoothness of the image and avoid that the image contains large regions without useful information, an interpolation process was performed. Interpolation is a technique that consists in dividing the range of interest into several subintervals smoothly with small degree polynomials.

For the interpolation process, the cubic splines technique was chosen; each interval is filled by a polynomial of third degree. The cubic spline gives an appropriate estimation for the interval. Figure 2 presents the result of the matrix shown in Fig. 1 with the normalized values for the maximum length of the matrix.

2.4 Correlation Sorting

The correlation sorting algorithm proposed by Costa et al. [16] was applied to rearrange the order of the image lines. In this approach, the cross-correlation calculation is used according to

$$R(i,j) = \frac{C(i,j)}{\sqrt{C(i,i) \cdot C(j,j)}}, \tag{1}$$

where each line of the image is compared with all the others to determine the highest correlation coefficient possible. Figure 3 shows the result of cross-correlation sorting applied

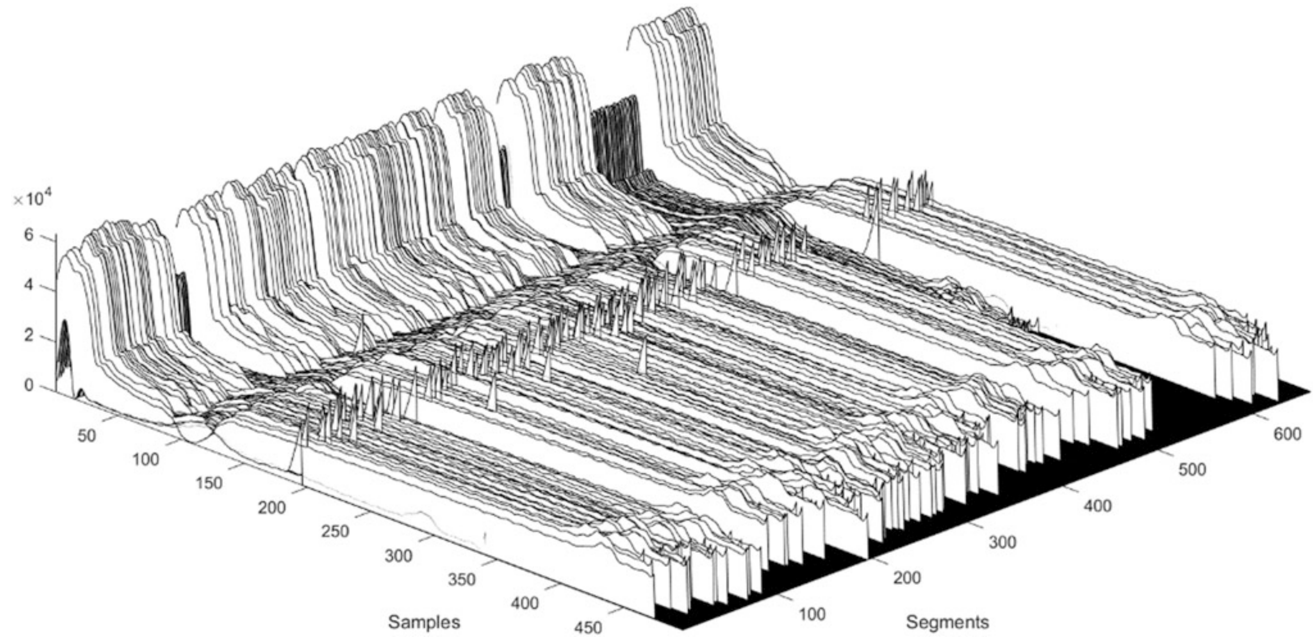

Fig. 1 Signal 119 segmented (3D view for better perspective)

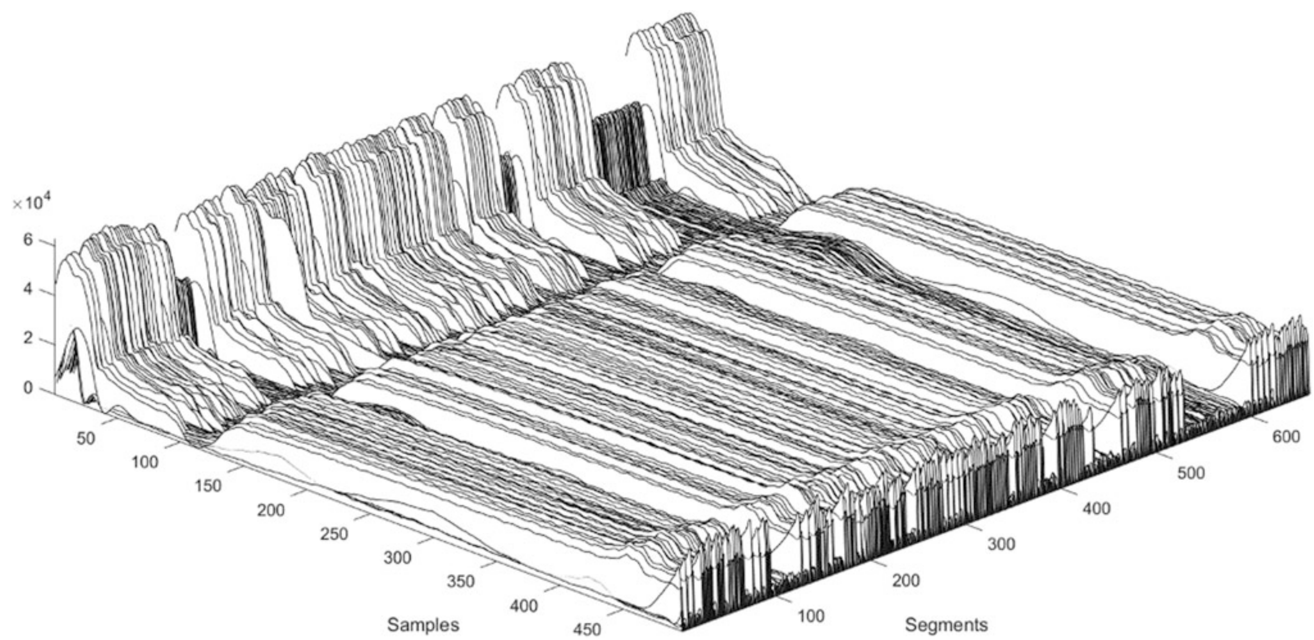

Fig. 2 Signal 119 interpolated (3D view for better perspective)

to the matrix in Fig. 2, showing a surface in which groups of segments exhibits high similarity to each other. Figure 4 is the actual image (i.e., two-dimensional) version of data presented in Fig. 3.

2.5 Compression Performance Metrics

In order to evaluate the proposed compression scheme, two consolidated performance metrics were used. First, the rate

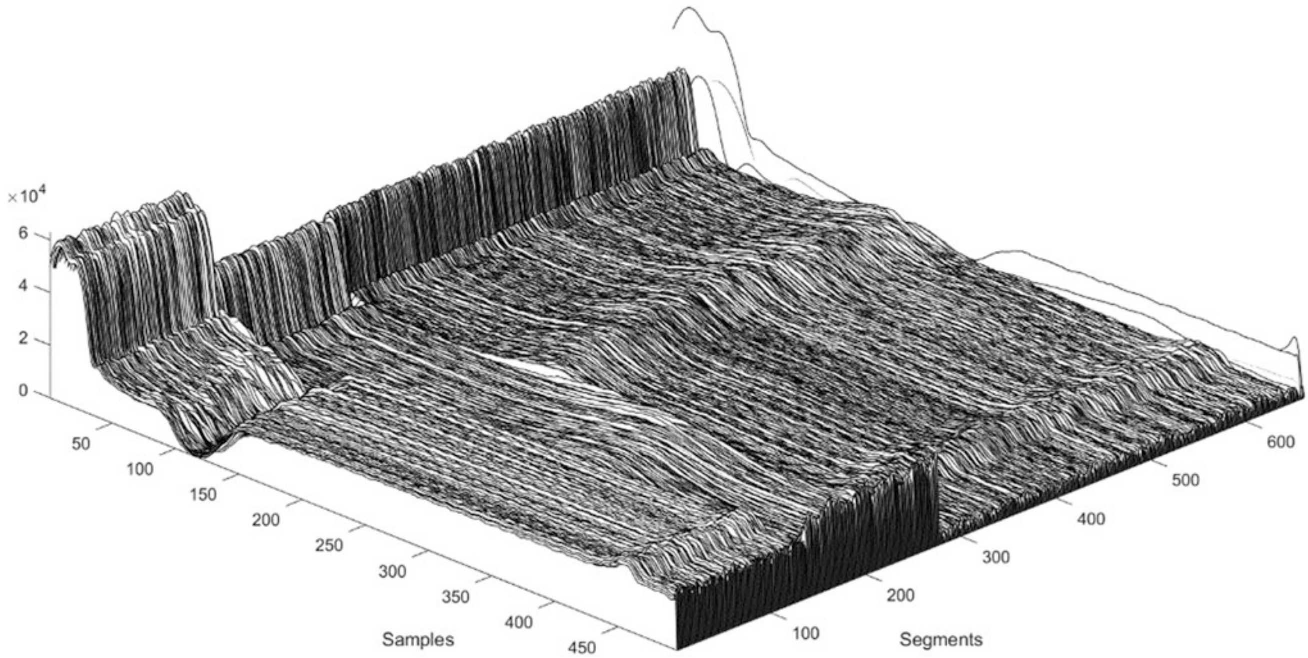

Fig. 3 Signal 119 interpolated and reordered (3D view for better perspective)

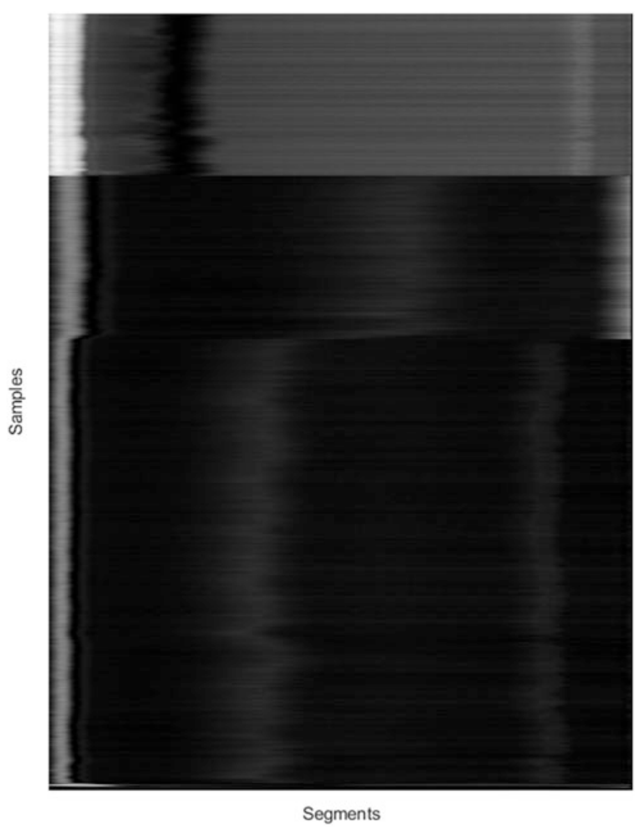

Fig. 4 Signal 119 interpolated and reordered in the 2D view provided to the encoder

metric was the Compression Ratio (CR) [6], which presents the relation of the compressed signal with the signal without any type of compression:

$$CR = \frac{O_S}{C_S}, \tag{2}$$

where O_S represent the number of bits needed to store the original samples and C_S represents the number of bits of the compressed file.

Second, to compare the quality of the reconstructed signal with the original signal (or the distortion caused by the lossy compression) we adopted the Percentage Root Mean Difference (PRD) [6]:

$$PRD(\%) = \sqrt{\frac{\sum_{n=1}^{N}(x[n] - \hat{x}[n])^2}{\sum_{n=1}^{N} x[n] - 1024}} \times 100, \tag{3}$$

where x represents the original signal, $\hat{x}$ represents the compressed signal and N is the number of samples of the signal segment, and the value of 1024 is the offset adopted in the MIT-BIH Arrhythmia Database [13].

3 Results

Figures 1, 2, 3 and 4, presented below, illustrate the procedures discussed in the previous section for the signal 119 in MIT-BIH Arrhythmia Database [13].

Table 1 Comparative with the main works using two-dimensional techniques for signal 100

Signal 100		
Algorithm	CR	PRD (%)
Lee et al. [2]	24	8.10
Chou et al. App [5]	24	4.06
Filho et al. [6]	24	3.95
Joo et al. [7]	24	3.53
Proposed	24	**3.14**
Filho et al. [6]	10	2.12
Joo et al. [7]	10	2.12
Proposed	10	**2.15**

Table 2 Comparison with the main works using two-dimensional techniques for the signal 117

Signal 117		
Algorithm	CR	PRD (%)
Lee et al. [2]	24	1.72
Chou et al. App [5]	24	1.64
Proposed	24	**1.25**
Chou et al. App [5]	13	1.18
Filho et al. [6]	13	1.07
Joo et al. [7]	13	1.06
Proposed	13	**0.87**
Bilgin et al. [3]	10	1.03
Chou et al. App [5]	10	0.98
Filho et al. [6]	10	0.86
Joo et al. [7]	10	0.85
Proposed	10	**0.76**
Bilgin et al. [3]	8	0.86
Filho et al. [6]	8	0.75
Joo et al. [7]	8	0.73
Proposed	8	**0.68**

Tables 1, 2 and 3 compare the results obtained by several works in literature, using CR and PRD, which are metrics widely used for authors in the field of biomedical signal compression.

Figure 5 shows the compression quality curve for signals 100, 117 and 119. Selecting the appropriate values on the curves in Fig. 5, were obtained the values presented in Tables 1, 2 and 3, in which the results of the present study are compared to reference articles in the area.

4 Discussion and Conclusion

The results of the proposed algorithm, in Tables 1, 2 and 3, shows that the proposed algorithm can outperform other results presented in the literature.

The present work proposed an ECG compressor implementation based on 2D coding through the HEVC-intra encoder and pre-processing techniques.

Table 3 Comparative with the main works using two-dimensional techniques for signal 119

Signal 119		
Algorithm	CR	PRD (%)
Bilgin et al. [3]	22	3.76
Proposed	22	**1.92**
Tai et al. [2]	21	2.17
Chou et al. App [5]	21	1.81
Filho et al. [6]	21	1.92
Joo et al. [7]	21	1.80
Proposed	21	**1.89**
Chou et al. App [5]	10	1.03
Filho et al. [6]	10	0.93
Joo et al. [7]	10	0.92
Proposed	10	**1.53**
Filho et al. [6]	8	0.74
Joo et al. [7]	8	0.73
Proposed	8	**1.48**

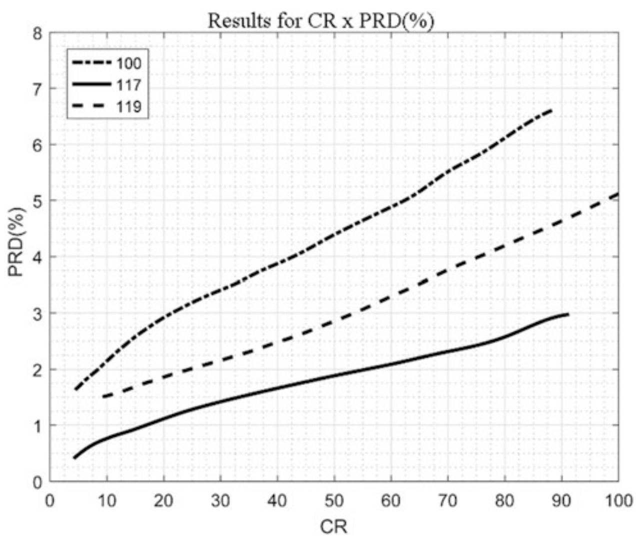

Fig. 5 Compression results for signals 100, 117 and 119

The results presented are comparable with the results presented in articles of great relevance in the area and also outperform some of those results. For some signals in the database the proposed approach based on HEVC-intra shows the best quality results, however in other cases presents a moderate lower quality.

As the HEVC-intra uses more modern techniques of image processing and compression than several other works on the literature, the lower quality at some points could be justified by the smaller amount of preprocessing used in the present work in comparison to the cited works.

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