ECG COMPRESSION USING ADAPTIVE VECTOR QUANTISER

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Abstract

In this paper, a new vector quantisation (VQ) scheme is proposed for ECG, which achieves a good quality of reconstruction, in addition to a high compression ratio. This is achieved by using a novel technique for forming input vectors from ECG, a new distortion measure and a simple adaptive codebook. To begin with, the data is segmented into beats. The segmentation requires the detection of no component other than the R-wave. The segmented beats are subjected to pole-zero modeling to generate a minimum phase model. The pole-zero vectors obtained from the model are input to the VQ coder. An adaptive codebook is used which can handle the abnormal ECG beats too. As the QRS zone contains the principal clinical information, the pole-zero values corresponding to this zone are given more weightage while generating the codebook.

Introduction

Efficient coding of the ECG is important in applications such as ambulatory monitoring, patient data bases, medical education systems, and transmission over telephone lines. The goal of any ECG compression scheme is to reduce the bit-rate significantly while keeping the signal distortion at a clinically acceptable level. This means minimising the distortion in the P-wave, QRS complex, and the T-wave, the features of interest in terms of clinical diagnosis.

Pole-zero models have been applied to model the ECG by a transfer function H(z), given by

$$H(z) = \frac{Y(z)}{X(z)} = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2} + \ldots\ldots\ldots\ldots b_q z^{-q}}{1 + a_1 z^{-1} + a_2 z^{-2} + \ldots\ldots\ldots\ldots a_p z^{-p}} \qquad (1)$$

where Y(n) is the ECG beat being modeled and X(n) is the impulse signal. The unknown coefficients a_i and b_j ($i=1,2,\ldots..p$, $j= 0,1,2,\ldots..,q$) are either constants or vary linearly with time and are to be estimated from the signal Y(n). The algorithm in [1] used Shank's technique [2] to pole-zero model the maximum and minimum phase components of the ECG. This technique required very high model orders of about 30 poles and 30 zeros. To achieve low model orders, the technique in [3] used discrete cosine transform to pre-process the beat before Steiglitz-Mcbride modeling (DCTSM). The efficacy of this method arises from the fact that the non-minimum phase ECG signal is transformed into a "near"-minimum phase signal, which can easily be modeled.

VQ is known to be an efficient compression scheme when a low bit rate is desirable. This fact has motivated several researchers to apply VQ to ECG. Cohen et al [4] treated the amplitude, position and width of the constituent waves (P, QRS, and T) as a vector and applied vector quantisation. In [5], multi-channel ECG is handled by applying classified vector quantization (CVQ) to the m-AZTEC parameters. The m-AZTEC is an extension of the AZTEC technique which was proposed for single channel ECG data [6]. However, these techniques were not successful as the features selected did not represent the ECG beat efficiently.

In each of the above ECG VQ coders, the vectors were formed in different ways. The technique proposed in this paper selects the pole-zero vectors as inputs to the VQ. The pole-zero vectors represent the ECG effectively and the clinically significant components are given due importance. This technique achieves a high compression ratio and a good quality of reconstruction as it exploits simultaneously the inter and intra beat correlations present in ECG.

Segmentation and Modeling of ECG

Cardiac cycles normally start with a P-wave, and end with a T-wave, with the QRS zone in the middle. For our convenience, we define an ECG beat as the signal that starts with the QRS zone, has the T- wave in the middle and ends with a P-wave. Recorded ECG is divided into R-R cycles by the QRS detection technique reported in [7]. 10% of current R-R interval is included before the R- peak and 10% of next R-R interval is removed at the end to form an ECG beat.

The model obtained through DCTSM is non-minimum phase for some ECG signals and then the dynamic range of the zeros outside the unit circle is very large. By making the input ECG beat Y(n) to be always greater than zero, the resulting filter model H(z) is always found to be a minimum phase function. This can be done by adding a DC shift to the original ECG signal. This doesn't affect the diagnostic value of the ECG. We modified all our ECG signals this way and found that the resulting model was always minimum phase. Fig. 1 shows the minimum phase model obtained for a typical ECG beat.

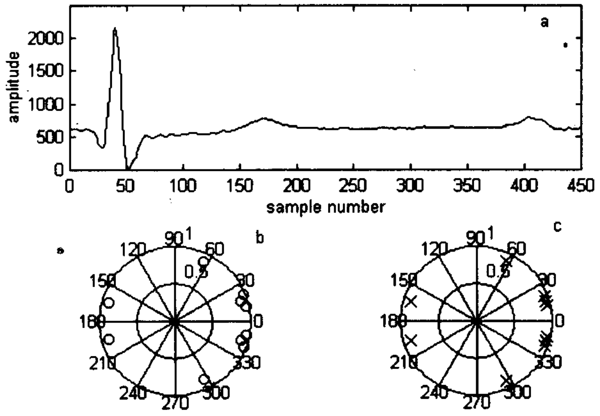

Fig. 1. Minimum phase model for ECG. a) Modified ECG beat b) its zero plot and c) pole plot.

Formation of Feature Vectors

Modeling of ECG beats with order (10,10) resulted in well separated complex conjugate poles and zeros. This model order is generally found to be sufficient to represent the clinically significant components in the beat. This is due to the fact that the IDCT of the impulse response of a second order system function with two complex conjugate zeros and two complex conjugate poles, gives a bell-shaped wave [3]. The QRS zone can be obtained by a combination of three bell shaped waves, the P wave by one and the T wave by another bell shaped wave. This motivated us to employ the pole-zero values of the model of order (10,10), as the feature vector for the vector quantiser.

The pole-zero values are converted to polar co-ordinates(r,θ). Only one half of the poles and zeros are taken that lie in the upper half of the unit circle. The elements are ordered in the vector according to the increasing value of their angles. With our choice of the ECG beats, the poles of QRS zone come first, followed by those of the T-wave and the P-wave. The vector consists of r-values of poles of the upper half of the unit circle, followed by the respective θ-values, and then the r-θ values of zeros arranged in a similar manner.

Adaptive VQ Coder

The Block diagram of the encoder is shown in Fig. 2. To code the pole-zero vectors efficiently, an adaptive VQ scheme similar to the speaker adaptive VQ [8] is used. Here, we form a first-in-first-out codebook, which is populated by quantized pole-zero vectors, of Q previous ECG beats, i.e.

$$CB = [\underline{X}_{n-Q}, \underline{X}_{n-Q+1}, \ldots\ldots, \underline{X}_{n-1}] \tag{2}$$

where Q is the size or depth of CB. When the incoming pole-zero vector is received, the index of that codebook entry is transmitted, which has minimum distortion with respect to the former. A weighted mean square error function, which gives more weightage to the QRS poles and zeros, has been used as the distortion metric. If $\underline{X}_{n-j}$ is the best estimate of X_n, then the prediction error vector is given by $E_n = X_n - \underline{X}_{n-j}$. The prediction error is quantized using a three bit optimal scalar quantizer. Fig. 3 shows the block diagram of the decoder. On receiving the transmitted index, the decoder outputs the corresponding codebook vector. The error is dequantised and added to the selected codebook vector to generate the reconstructed pole-zero vector. The difference between the gain of the model and the average gain having been transmitted to the decoder, the actual gain of the model is calculated. The difference between the original period and average period having been transmitted to the decoder, the actual period of each beat is obtained. The model impulse response, of length same as that of the beat is found. The IDCT of the impulse response gives the reconstructed ECG.

Results

The proposed method was tested using ECG data taken from Massachusetts Institute of Technology database. Fig. 4 illustrates a sample ECG signal and also the signal reconstructed using the proposed technique with a model of order 10 and a codebook of size 32. To evaluate the performance of the coder, we calculate the compression ratio, and an error measure as defined below.

A. Compression Ratio(CR)

$$CR = \frac{b_0 \sum_{i=1}^{N_T} T_i}{N_T(\log_2 S + b_1 + b_2 + b_3)} \tag{3}$$

where N_T is the total number of beats transmitted, T_i is the period of the i^{th} beat, S is the size of the beat adaptive codebook, b_0 , b_1 , b_2 , b_3 are the number of bits used to quantise the digitised ECG samples, the error vector, the gain factor difference and the period difference, respectively.

B. Normalised Root Mean Square Error (NRMSE)

The expression for this error measure is given by

$$NRMSE = \sqrt{\frac{\sum_{i=0}^{N-1}[x_o(i) - x_r(i)]^2}{\sum_{i=0}^{N-1} x_o^2(i)}} \tag{4}$$

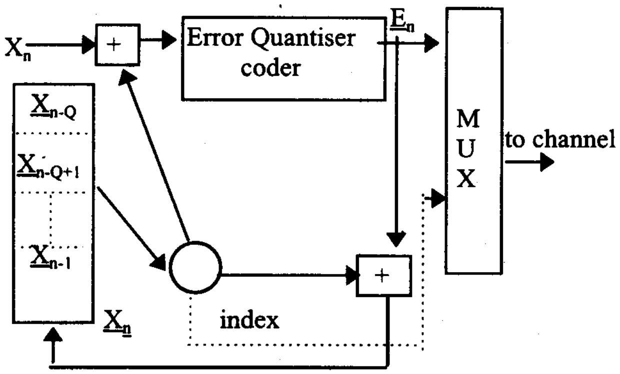

Fig. 2. Block Schematic of the Encoder

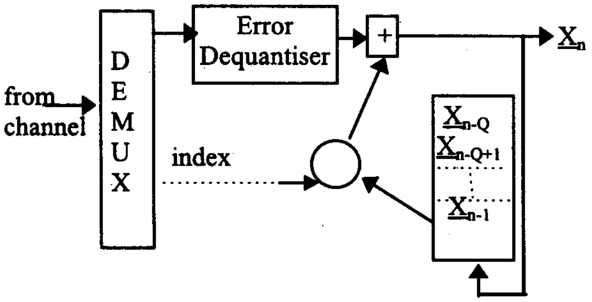

Fig. 3. Block Schematic of the Decoder

where N is the total No. of samples being transmitted, and $x_o(i)$, $x_r(i)$ are the i^{th} samples of the original and reconstructed ECG respectively.

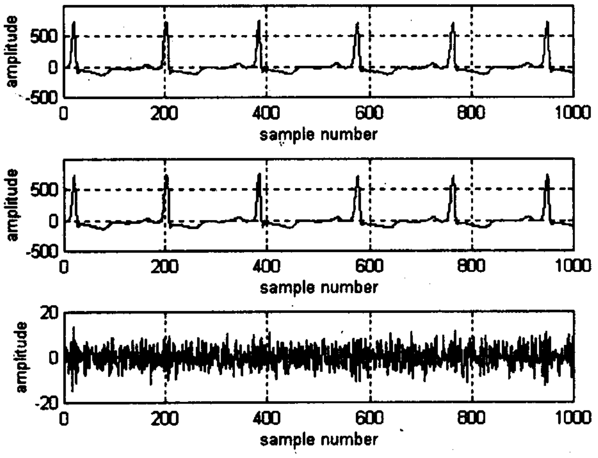

Fig 4. Results of our technique. a) Original ECG b) reconstructed signal, and c)reconstruction error

Table I shows the performance of the proposed coder for a codebook of size 32 and a model of order 10 for 3 different subjects.

TABLE I
Performance figures for 3 subjects

	CR	NRMSE %
1	120	6.94
2	110	6.87
3	130	7.04

Conclusions

A novel selection of feature vector for a ECG VQ coder is proposed. This technique gives a compression ratio and a fidelity of reconstruction higher than most of the reported techniques. However, the technique fails for some ECG beats, whose model contains real poles and zeros. These beats should be separately coded.

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