A New Technique for Progressive ECG Transmission using Discrete Radon Transform

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***Abstract*—**The aim of this paper is to present a new method which can be used for progressive transmission of electrocardiogram (ECG). The idea consists in transforming any ECG signal to an image, containing one beat in each row. In the first step, the beats are synchronized in order to reduce the high frequencies due to inter-beat transitions. The obtained image is then transformed using a discrete version of Radon Transform (DRT). Hence, transmitting the ECG, leads to transmit the most significant energy of the transformed image in Radon domain. For decoding purpose, the receptor needs to use the inverse Radon Transform as well as the two synchronization frames.

The presented protocol can be adapted for lossy to lossless compression systems. In lossy mode we show that the compression ratio can be multiplied by an average factor of 2 for an acceptable quality of reconstructed signal. These results have been obtained on real signals from MIT database.

***Keywords*—**Discrete Radon Transform, ECG compression, synchronization.

I. Introduction

IN some clinical applications, the ECG signal needs to be transmitted by means a given network (Internet, Intranet, Wireless, Bluetooth…). However, the amount of the transmitted data may be in some cases not suited for a given bandwidth allowed by the network. In fact, the information increases considerably when increasing the number of channels, the resolution and the sampling frequency. Therefore, the compression becomes in this case necessary and the required property of any compression method should achieve a high-quality reconstruction of the ECG at low bit rates.

Commonly, the ECG compression techniques are classified in three broad classes:

- Direct methods,
- Parameter extraction methods,
- Transform-based methods.

In the direct method class, the original samples are not subject to any transformation. The related methods are based on the extraction of significant samples using time-domain algorithms. One can refer to the Turning Point (TP) method, the Amplitude Zone Time Epoch Coding (AZTEC) method, or the Coordinate Reduction Time Encoding System (CORTES) [1][2]. In the second class, the approaches commonly used, extract some features from the ECG signal which should be used for the reconstruction purpose. One can name, for instance, the linear prediction method and neural networks methods [3], [4].

Finally, in the last class, the signal is transformed and the compression is performed in another domain. Many transforms have been used as a compression kernel. One can evoke, for example, Karhunen-Loève Transform [5], Fourier Transform [6], Discrete Cosine Transform [7], Walsh Transform [8], Polynomial Transform [9] [10] and Wavelet Transform [11]-[17].

Using the transform based-method, we are interested in this paper, only in the methods those transform the ECG signal to an image before using any codec [18], [19], [20], [21]. In addition, the idea here is to make the transmission of the ECG progressive, in the sense that user can get (on request) the details of any selected ECG beat. This can be performed by sending the difference signal between the reconstructed signal and the original one. The protocol of transmission becomes in this case interactive.

In this work, the ECG signal is preprocessed by transforming it as an image. Each image row contains one beat. After synchronizing the beats, the image is then transformed by means a Discrete Radon transform (DRT).

As it is well known, Radon transform or specifically, the inverse Radon Transform is basically used for image reconstruction purpose, basically in Computerized Tomography (CT), Magnetic Resonance (MR), Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET).

The present paper is organized as follows. In the next section, we briefly describe the Radon Transform and the discrete version of Radon Transform principle [22]. In section 3, we explain how the technique is used for the progressive transmission purpose. Section 4 is devoted to the presentation of some experimental results obtained from some well known ECG databases. Finally, section 5 concludes this work.

II. Radon Transform and its Discrete Version

The Radon Transform of a given two-dimensional continuous function, denoted $I(x, y)$ is given by integrating values of I along slanted lines. The position of each line is determined from its slope p and its offset τ (see Fig. 1).

For each given direction, a specific signal, called projection, is computed. Hence by rotating the lines, one can obtain a set of projections that should be used for the

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reconstruction process.
Radon Transform is defined by:

$$\tilde{R}(p,\tau) = \int_{-\infty}^{\infty} I(x, px+\tau)dx \quad (1)$$

For a given digital image $I(x_m, y_n)$, the following approximation is achieved:

$$\tilde{R}(k,h) = \sum_{m=0}^{M-1} I(x_m, [p_k x_m + \tau_h]) \quad (2)$$

k=0…K-1, h=0…H-1

$\tilde{R}(k,h)$ is called sinogram.

[.] means rounding the argument to the nearest integer. In this work the Nearest Neighbour interpolation technique is used.

III. Progressive ECG Transmission Using DRT

A. *Beat detection*

As it has been mentioned in the introduction, the technique presented in this paper, processes the ECG as an image. The first step when recording this signal consists in detecting automatically each beat. However, this can be achieved using some known algorithms not described in this paper since it is not the main objective of our work.
When detecting the beats, a specific classification is required. In other words, beats having closer shapes should be gathered in the same matrix (Image). For instance, if the ECG signal contains normal and Premature Ventricular Contraction beats (PVC), two images are then created. This, of course, can be generalized when the ECG signal is containing *P* different beats, which leads systematically to *P* images.
As it is well known, the ECG signal is usually none periodic, basically for the pathological case (for instance, the arrhythmia). So, during the detection/segmentation phase, the durations of different segments are varying. Hence, in order to compact them into a matrix, one can extrapolate the shortest segments according to the longest ones so that number of samples in each segment will be identical.

If we denote by $x(n)$, the ECG recorded signal and by M, the number of segments, a 2 D array is obtained having M rows corresponding to different beats, and N columns corresponding to the number of samples in each segment.
The following corresponding matrix is then constructed:

$$\mathbf{I} = \begin{bmatrix} x_1(0) & x_1(1) & \cdots & x_1(N-1) \\ x_2(0) & x_2(1) & \cdots & x_2(N-1) \\ \vdots & \vdots & \ddots & \vdots \\ x_M(0) & x_M(1) & \cdots & x_M(N-1) \end{bmatrix} = \begin{bmatrix} \mathbf{x}_1^t \\ \mathbf{x}_2^t \\ \vdots \\ \mathbf{x}_M^t \end{bmatrix} \quad (3)$$

B. *Beat alignment*

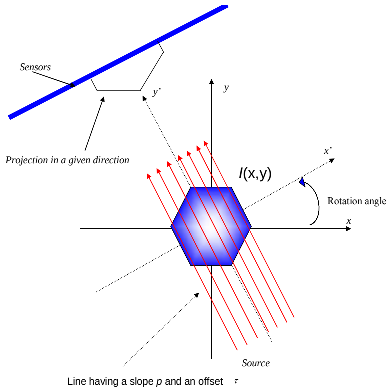


Fig. 1 Schematic illustration of Radon Transform in Tomography

Since the ECG is processed as an image, it is important that the frequency composition of the image to be a narrow-band. To do so, one can synchronize or align the beats simply by maximizing the cross-correlation function between successive beats.
The alignment means that each beat has to be translated by an optimal delay denoted by d_j for *j=0,…M.*
Hence, each line of the Matrix **I** requires a circular translation. This leads to a modified matrix, denoted in this paper by $\mathbf{I}_{sync.}$. The delay values should be necessary used for the reconstruction purpose. They will be stored in a specific frame.

C. *DRT of the aligned ECG image*

One of the important properties of RT is the duality between the space domain and the RT domain. For instance, a point in the space domain is transformed to a Line in the RT domain. In the other hand, a line in the space domain is transformed to a point in the RT domain. This can be illustrated in the discrete case (see Fig. 2 and 3).

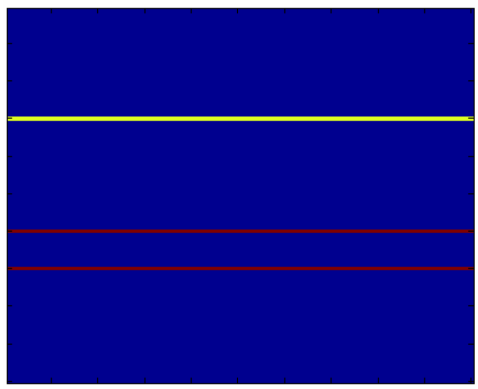


Fig. 2 Example of an image, containing three horizontal lines

This property will be transposed to our case, essentially by the fact that the DRT is to be applied on synchronized beats (considered as a set of lines). To illustrate this, let’s consider a perfect case from a simulated ECG beat as shown in the Fig. 4.

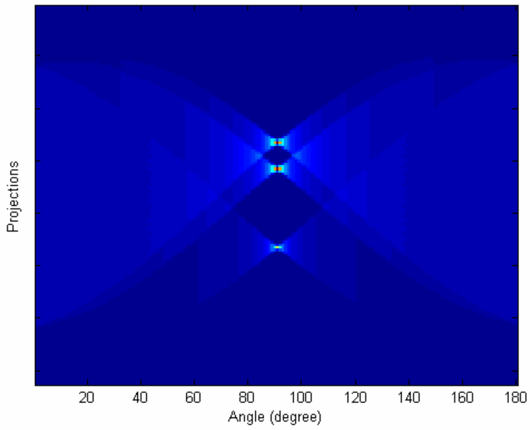


Fig. 3 Discrete Radon Transform of the synthesized image,

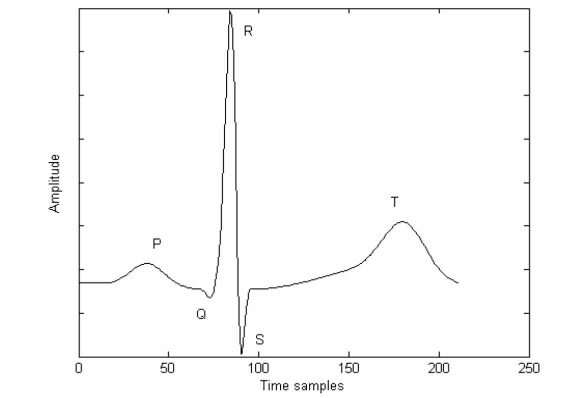


Fig. 4 Realistic simulated ECG beat, showing the waves P, Q R S and T

From this signal, an image or a bidimensional representation is generated by simulating a set of identical beats (Fig. 5). As it can be shown from the sinogram represented in Fig. 6, the main energy in Radon Transform domain is locally compacted.

D. Transmission of the ECG signal

Since the sinogram obtained by using the DRT, is characterized by a concentration of the energy on a given location, it will be more interesting to transmit only the most dominant area instead transmitting the whole sinogram. In addition, one has to transmit:

1. A frame (F_D) containing the delays used for the synchronization purpose.
2. A frame (F_L) containing the locations in time of each ECG beat (required when the ECG signal contains more than one specific shape).

Example of application:

If we consider an ECG signal containing Q_1 beats having closer shapes (S1) and Q_2 beats having closer shapes (S2). One has to construct:

1. An image I1 containing all beats of shapes S1, a frame F_D_1 and a frame F_L_1.

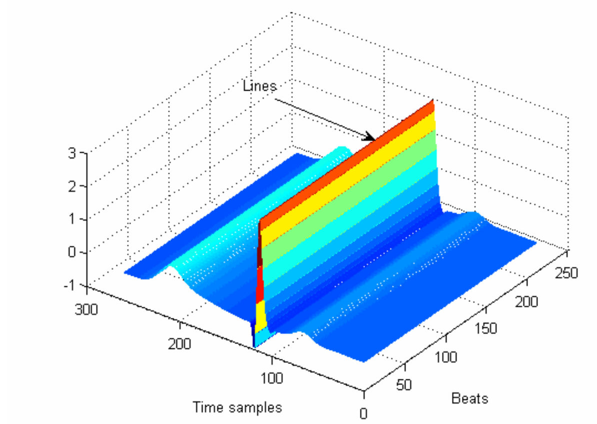


Fig. 5 A bidimensional representation of a set of synthesized ECGs, showing line aspect (ideal case)

2. An image I2 containing all beats of shapes S2, a frame F_D_2 and a frame F_L_2.

We start transmitting the most significant sinogram energy corresponding to both I1 and I2 DRT as well as F_D_1, F_L_1, F_D_2 and F_L_2 frames. At the reception, an approximated signal is obtained using the inverse Discrete Radon Transform (by means a filtred backprojection algorithm [23]). Starting from this point, depending on the ECG quality needed, the user can select (on its screen) the ECG segment to be improved.

In this case, a difference signal (between the original and the reconstructed) is sent and added to the received signal. This protocol makes the transmission interactive (on request), see Fig. 7.

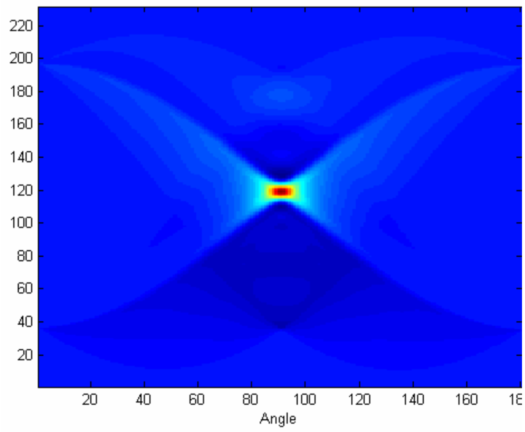


Fig. 6 Discrete Radon Transform of the synthesized ECG image

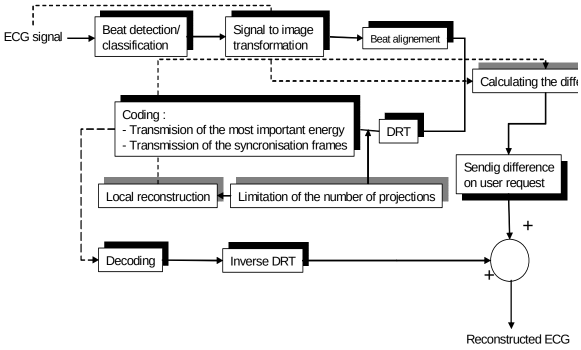


Fig.7. Transmission and reception of an ECG signal

IV. Application on Real Signals

The MIT-BIH arrhythmia database is commonly used to evaluate the performance of compression algorithms. The duration of each record in the database is at least 30 minutes, acquired at 360 samples/s and represented using 11 bit resolution.

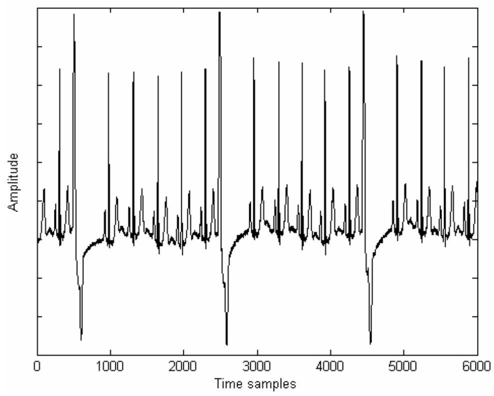


Fig. 8 Real signal MIT119 from MIT-BIH database

In this paper, the evaluation is not limited only to the MIT-BIH arrhythmia database, but it has been extended to the ST change database and Atrial Fibrillation one. For illustration purpose, only the 119 record will be considered (see Fig. 8). This signal has the particularity to be composed of a mixture of two beats. The first one could be considered as normal, whereas the second one is generally referred as PVC.

When transforming this signal to an image as presented in Fig. 9 (a), one can notice that the beats are randomly distributed due the arrhythmia feature. Moreover, when calculating the DRT, the sinogram, presented in Fig. 9 (b), provides another aspect of the image where the concentration of the energy remains randomly distributed.

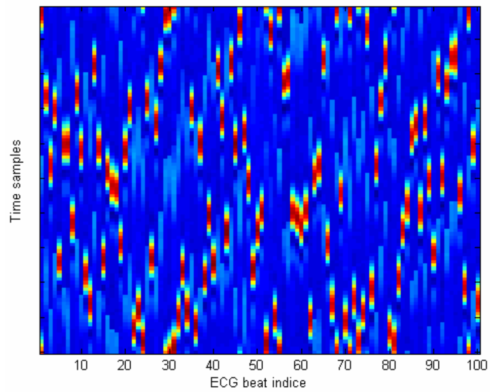
Since the approach presented in this paper consider that the ECG signal should be pre-processed by:

1. Separating normal beats/abnormal beats.
2. Transforming each class of beats to images, and then synchronizing the whole beats.

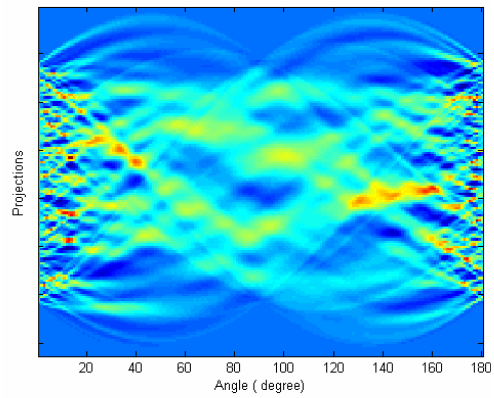
DRT is applied separately for each image, and then transmitted according to the protocol described in the example of the previous section.

By analyzing the sinograms in Fig. 10 (b) and Fig. 11 (b) corresponding respectively to the DRT of synchronized (aligned) normal beats (see Fig. 10 (a)) and the DRT of synchronized PVC beats (see Fig. 11 (a)), one can notice from the sinograms that the energy is mainly gathered in a given location. Hence, instead transmitting (coding) the whole sinogram, only few projections (most significant ones) should be transmitted. This is aspect highlighted in the figures by means of windows.

The Table 1 gathers the performances of the proposed technique when coding and transmitting only the projections of ECG signals. The quality of the reconstructed signal (without sending the difference signal) is evaluated by means the Percent Root-Mean–Square Difference (PRD), expressed in % and defined by:



(a)



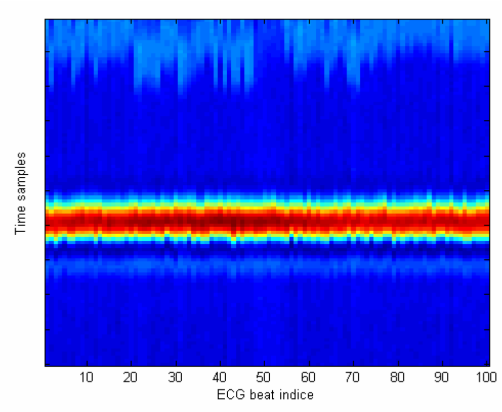
(b)

Fig. 9 (a) ECG transformed to an image, (b) DRT (sinogram) of the ECG image

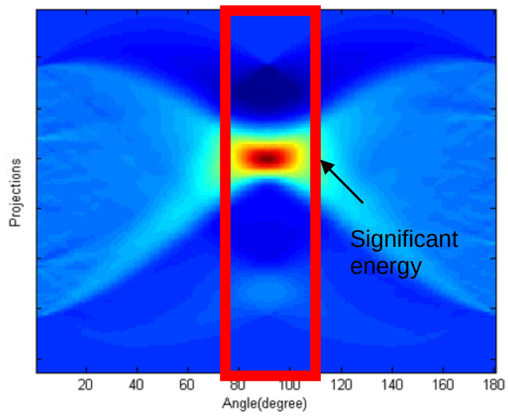
$$PRD = \sqrt{\frac{\sum_{n=1}^{N}(x(n)-\hat{x}(n))^2}{\sum_{n=1}^{N}(x(n)-m_x)^2}} \times 100 \qquad (4)$$

where $x(n)$ is the original signal and $\hat{x}(n)$ is the reconstructed signal.

m_x is the mean of the original signal.



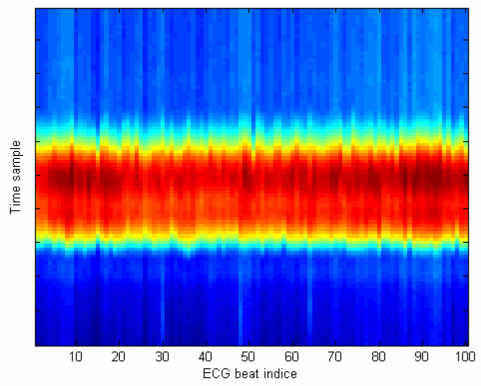
(a)



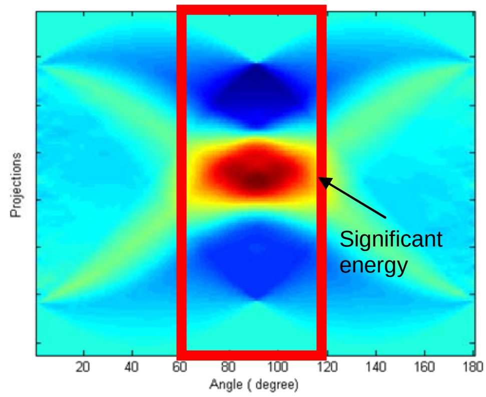
(b)

Fig. 10 (a) Normal ECG image after alignment, (b) DRT (sinogram) of the normal ECG image

For a given acceptable quality, one can notice that the ratio, calculated between the number of ECG beats and the number of the transmitted projections, is always greater than 1. This ratio can generally sometimes be greater than 2 which means that one can transmit only half the data to get an acceptable ECG signal in terms of quality as represented in Fig. 12. The ratio can be improved more and more if the ECG signal is stationary on a long duration. In the extreme case, one can consider the example, where the whole beats are identical. In such situation, only one projection is required to reconstruct the ECG signal.



(a)



(b)

Fig. 11 (a) PVC ECG image after alignment, (b) DRT (sinogram) of the PVC ECG image

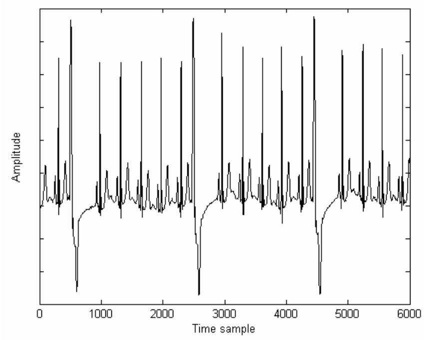


Fig. 12 Reconstructed ECG signal (MIT119)

V. Conclusion

In this paper we have presented a specific technique for progressive transmission of ECG. The technique consists in preprocessing the ECG image by means a DRT. We have shown that when the ECG beats are aligned, DRT leads to a dense representation in this domain. Furthermore, we have seen that it is not necessary to transmit the whole projections, since only the most significant ones allows an acceptable reconstruction in terms on quality (basically visually). The method can be suited and particularly interesting when a transmission on narrowband network is required. Since the proposed technique processes a signal as an image, coding it using some well known standards as (JPEG 2000) will be interesting. Another idea (independently) from the transmission aspect consists to raise the following question: Why not analyzing the ECG as an image in Radon transform domain rather analyzing it directly in the time domain? We think that this new vision to analyze signals can be useful for extracting some features not easily observable using classical techniques, mainly for pathology identification.

Finally, we have tried in this paper to submit the main idea and we believe that future works will clarify other interesting aspects.

TABLE I
PERFORMANCES OF THE PROPOSED METHOD ON VARIOUS PATHOLOGICAL ECG SIGNALS

ECG reference	Pathology	Database	Frequency sampling	Ratio: Nbr. ECG beat signal/ Nbr. Proj.	PRD
Mit302	ST segment change	ST change database	360	2	5
Mit119	With uniform PVC	Arrhythmia database	360	1.8	3. 8
Mit 109	With multiform PVC and Fusion PVC	Arrhythmia database	360	2.1	3.9
Mit105	With PVC uniform, high grade noise and artefact	Arrhythmia database	360	1.9	4.8
Mit04908	Atrial fibrillation	Atrial Fibrillation	250	2.2	2.5

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