A novel method to extract ECG morphology from scanned ECG records

Article · August 2011

DOI: 10.1109/DSR.2011.6026803

3 authors:

Vani Damodaran
M.S. Ramaiah Institute of Technology

Poonguzhali Srinivasan
Anna University, Chennai

Srinivasan Jayaraman

An Improved Method for Digital Time Series Signal Generation from Scanned ECG Records

Prashanth Swamy, Srinivasan Jayaraman, M.Girish Chandra
TCS Innovation Labs, Tata Consultancy Services
Bangalore, India
{prashanth.swamy, srinivasa.j, m.gchandra}@tcs.com

***Abstract*— Archiving the paper Electrocardiogram (ECG) trace as an image in hospitals and clinics is a regular practice to maintain the patients' history. However, it requires immense storage space and manpower for storage and retrieval of the patient records. In this paper we have proposed an improved algorithm for the existing paper ECG trace to digital time series with adaptive and iterative image processing techniques. We have tested our algorithm with a number of ECG sheets printed from 12-lead ECG equipments. Further, the proposed technique is enhanced to calculate the heart rate from the obtained time series to facilitate the evaluation of the methodology. Compared with the manually obtained heart rate, the methodology shows an accuracy of 95%, demonstrating the usefulness of the approach. Also, elaborate experimentation with the algorithm has brought out the robustness of the methodology in handling ECG traces from different sources.**

Keywords – ECG, ECG to Digital, Radon transforms, Adaptive Binarization, Iterative morphological image processing, Axis identification, Heart Rate

I. INTRODUCTION

Cardiovascular disease (CVD) is the one of the biggest health problem in Indian health care and around the world as well [2]. Monitoring heart helps to determine the existing and predict impending heart problems for cardiac patients. Electrocardiography (ECG) has been used in clinics for the diagnosis and monitoring of heart for almost a century. It remains the best and least invasive method for the task it performs. Due to its importance and a long journey in healthcare, ECG volume in hospital has increased tremendously.

Conventionally, each ECG has to be printed on a thermal paper and stored in the hospital for further diagnosis. In highly populous countries like India and China, immense storage space is required for storing the records of every patient. Retrieving the record from the archive is equally time consuming and laborious. Converting ECG records into a digital time series signal reduces the physical storage space. Further, with the appropriate annotation of the time series data, the retrieval of the requisite information can be made quicker and accurate.

Some of the research works in the direction of ECG digital time series signal extraction already exist. [1, 3, 5, and 9]. In [9], Kao *et. al.* morphological approach is used to remove the background grid from the ECG. An XOR operation is performed on the binary image's first periodic distance vertical direction (PDVD) and its shifted version. For it to work successfully, accurate estimation of PDVD is necessary which in turn strongly depends on the binarization of the image. In [5], Chebil *et. al.* perform binarization of the scanned image using appropriate thresholds. Since the thresholds are not selected based on the nature of the image, there is a loss of information in the extracted signal. In [1], Gomes *et. al*. extract the signal by discarding the axis and performing a median filtering operation on the resulting image. The removal of the axes leads to the additional difficulty in obtaining the ECG morphological details, which are essential for automatic report generation.

It is to be noted that, there exists a high probability of occurrence of printed characters and symbols (annotation) with ECG images. In such cases we require robust and effective algorithms to filter noise, remove printed characters and discard background grid from the ECG signal. All the existing techniques, briefed earlier, use morphological operations such as erosion, dilation, thinning etc, to extract the ECG trace from the background.

In this paper, we propose an improved methodology to extract the digitized version ECG time series. As a novelty, we are using the Radon transform for de-skewing the scanned images. Even though the conventional morphological techniques are adapted, they are applied in an iterative fashion on the binarized de-skewed images. This results in more accurate extraction of the time series. Further, a simple and useful way of axis identification is proposed.

The paper is organized as follows. Section II gives an overview of the method for converting scanned ECG documents to Digital time series signals. In Section III, results are discussed. Finally, Section V conclusion and future work of this paper.

II. METHODOLOGY

12 lead ECG signals were recorded at 25mm/sec and printed in thermal paper. These stored paper ECG trace is scanned at 600 dpi (dots per inch) black and white images and stored in jpeg format. Radon transform is applied on these images to detect and correct the skewness, which is incurred during the scanning process. The de-skewed image is adaptively binarized by choosing local thresholds. To limit the area to be binarized, the image is iteratively filtered by morphological filters. Each time the image retained is a cropped version of the original image. An envelope detection

978-1-4244-6776-1/10/$26.00 ©2010 IEEE

operation has been performed on the resultant binary ECG image to yield the upper and lower boundaries. The pixel values are then averaged to obtain the Digital ECG signal. The digital signal is windowed and resampled in accordance with the ECG record as shown in Figure. 1.

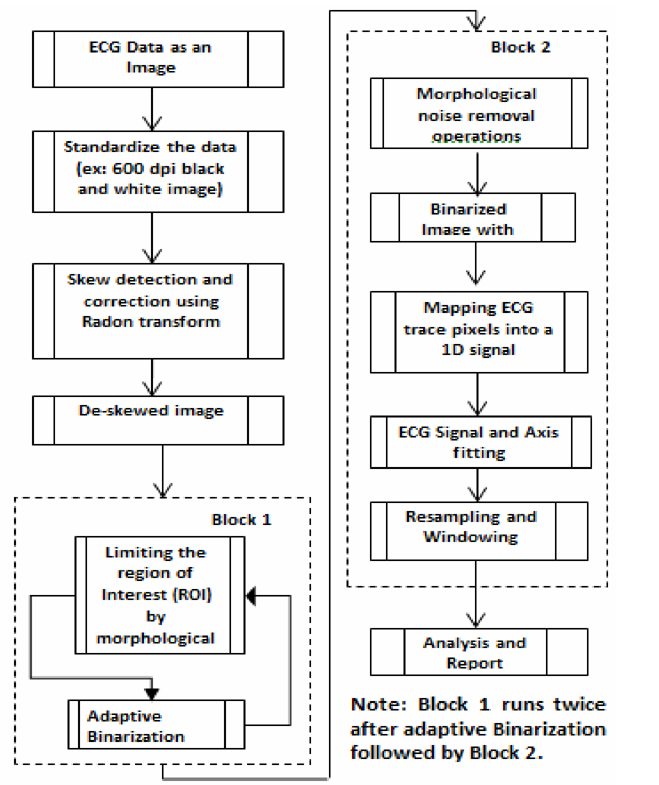


Figure 1 Overview of the digitization process from the scanned ECG.

A. Scanning and Standardization

The data obtained through thermal ECG papers needs to be scanned. In the present work, scanning resolution is fixed at 600 dpi for a black and white scan together with the JPEG format. These choices are made keeping in mind, the necessity to use lesser memory space. Table 1, lists out various scanning resolution and formats that that can be handled by the algorithm proposed.

TABLE 1. VARIOUS SCANNING RESOLUTION AND ECG TRACE FORMAT

Scanning Resolution (in dpi)	Type/Color	Image Format
200	True color	Jpeg/Tiff/Bmp/Png
300	Gray scale	Jpeg/Tiff/Bmp/Png
600	Color, Gray scale, B/W	Jpeg/Tiff/Bmp/Png

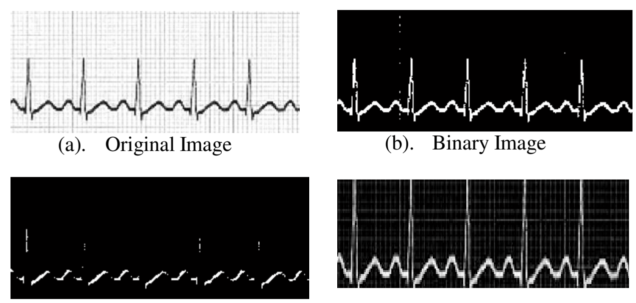
B. Skew Detection and Correction using Radon Transform

Scanning process of paper ECG may results in image skewness occurrence either due to human error or faulty scanners. In order to extract faithfully the ECG signal from images, the skewness has to be eliminated. To remove the skew [8], an axis is required. Here, in this work, we have applied Radon transform [6] to find the angle of skewness. The skew angle has been selected, based on the maximum variance.

C. Adaptive Binarization and Iterative Morphological operations

Our next objective is to binarize the image. Extracting the ECG signal from the image depends on the accuracy with which it is separated from the rest of the attributes present in the image like grid lines, textual characters, salt and pepper noise that occurs during scanning etc. From elaborate experimentation, it is observed that, using various image processing filters and tweaking the thresholds, could not eliminate the noise completely from the ECG signal.

In this work Otsu's algorithm [7] has been performed for image adaptive binarization. Adaptive threshold technique for image binarization yields better results compared to global thresholds. This process of adaptive binarization ensures that the threshold is selected based on an active signal region using morphological operation and not on the entire image.



(a). Original Image
(b). Binary Image
(c). Dilated Image
(d). Clipped Image

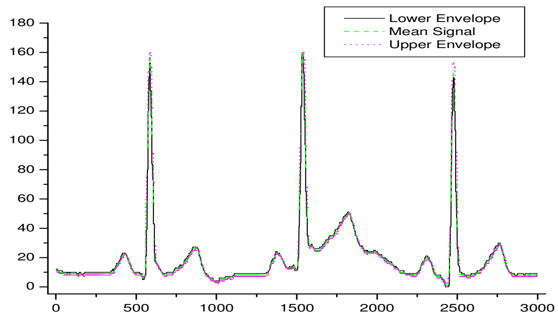
Figure 2 Iterative Morphological Operations

Morphological operations include dilation and erosion. [7] as shown in the figure 2 (c). Erosion operation on the binary image results in the loss of ECG signal as shown in Figure 2c. However, during this process of erosion, we record the upper and lower limit in the Cartesian coordinate. The boundary limit values are assigned as threshold and the image clipping operation has been performed on the ECG trace. The clipped image is again fed back to the adaptive binarization algorithm and the whole process is repeated again. This methodology reduces the original image to the requisite binarized image containing the useful information. Further this has been achieved through reduced processing time.

D. Envelope Detection and Axis Identification

The result as shown in fig 2 (b), contains only the binary ECG trace whose thickness is more than a single pixel. An envelope detector is applied in order to obtain a time series. In an envelope detector, the image is scanned column wise, at each column the uppermost and lowermost non zero values are recorded. Plotting all the upper and lower bound values, we obtain upper and lower envelopes of the ECG signal respectively. Fig 3 (a) shows an original grayscale ECG trace. Fig 3 (b) shows its corresponding envelopes.

(a). Original scanned ECG



(b). Digital Signal

Figure 3 Digital ECG Signal: (a) Original scanned ECG image of size 3000x250 pixels. (b) Digital signal envelopes of the original scanned ECG image.

The mean of ECG signal is represented as

$$X = [X_{ub} + X_{lb}]/2 \tag{1}$$

Where, X is the mean ECG signal, X_{ub} and X_{lb} is upper and lower envelope of ECG signal respectively

Axis identification plays a vital role in further diagnosis and automatic report generation of the ECG records. Initial the test square pulse present in the starting of any ECG trace is used as reference for the axis. However, in most practical scanning procedures and data capture, square pulses are often absent due to the sheer length of the ECG paper. In order to overcome this, a novel and simple technique to identify the axis is proposed in this paper.

The obtained signal X can be represented as X = $[x_1, x_2, x_3....x_n,]$, where the values of each element in the vector correspond to a ECG signal pixel location. By observation, it was found that the most significant and recurring pixels are usually represents the axis of the signal along the horizontal. As the signal obtained can be treated as a vector, the most axis is obtained by calculating the mode of the vector. Hence, we can represent it as:

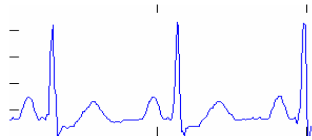
$$ECG\ Axis = Mode(X) \tag{2}$$

In most cases, the axis will be non-zero; therefore there is a need to offset the axis to the horizontal zero in order to standardize the signal. Equation 2 describes the offset process.

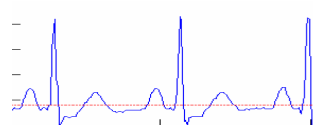
$$ECG_{\ zero\ axis} = Offset\ (Mode(X)) \tag{3}$$

(a). Original ECG image

(b). Binary Image



(c). Digital ECG signal



(d). Digital Signal with reference axis

Figure 4 (a,b,c). ECG extraction sequence (d) plotting of reference axis for the digital ECG signal

E. Normalising and R-peak Detection

The R-peaks which have maximum amplitude in an ECG signal which is extracted by differentiating the ECG signal. Taking the first derivative of the ECG signal and discarding the negative values provides the location of the R-peaks. Subsequently, the number of peaks is used to calculate the heart rate.

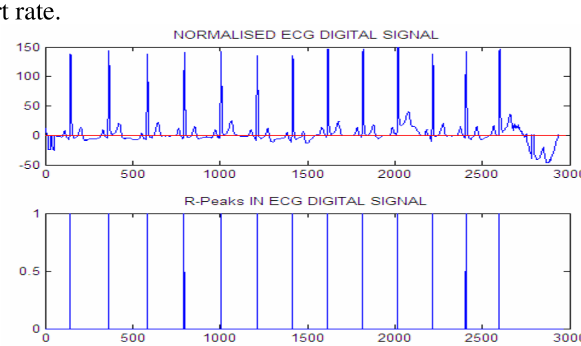


Figure 5 Normalized ECG signal with reference axis and location of the corresponding R-Peaks. Normalized signal with reference axis is used to extract the R-peaks. All peak locations are represented as 1's in the x-axis ranging between – to 3000.

III. RESULTS AND DISCUSSIONS

The database used consists of ECG records of ten individuals, scanned at 600 dpi black and white mode and stored as JPEG image. Each ECG records have 12 leads of information and ECG lead traces are segmented manually. All segmented images are standardized to 3000 x 250 pixels automatically within the algorithms designed. The size was chosen based on observations drawn out of multiple sized ECG trace images. Each ECG image consisted of 10 seconds of recorded ECG trace with 50 large squares and each large square [6] is 200 milliseconds.

Kao *et. al.* [9] work uses PDVD, to extract the ECG trace successfully, grid removal process high depends on scanning resolution. Poor scanned ECG paper trace leads to loss of vertical grids that result in wrong calculation of PDVD. In our method, grid lines are removed using morphological filtering techniques. In another study Chebil *et. al.* [5] uses global threshold method for binarization. The global threshold is chosen randomly. Random thresholding method treats the noise and signal as same that result to poor binarized image. In addition, this method is more complex and requires more computational time as well. Our technique adaptively chooses threshold based on the active signal region using Iterative morphological operation.

To evaluate and calculate the accuracy of the digitization process, heart rate has been used. The distance between R-R intervals is extracted and heart rate calculated based on the database standards. Table II shows the heart rate calculated using our algorithm and manual process.

TABLE 2. HEART RATE CALCULATION OF THE DIGITAL ECG SIGNAL OF THE PATIENT

ECG Record	No of R-Peaks Detected	Actual R-Peaks observed manually	Heart Rate	Actual Heart rate observed as printed on the ECG record
Data 1	8	8	92	96
Data 2 (lead 2)	13	13	78	83
Data 2 (lead 3)	13	13	78	83
Data 3	10	11	60	67
Data 5	12	13	72	78
Data 1 *	7	11	42	66

* Corrupted ECG trace with noise due to poor scan

The algorithm is able to achieve about 95% accuracy in converting an ECG record to a digital time series signal.

IV. CONCLUSION AND FUTURE WORK

An improved method for extraction and digitization of ECG signal from various sources such as thermal ECG printouts, scanned ECG and captured ECG images from devices is proposed. The methodology produced a reasonably accurate waveform as tested through heart rate calculations. Further work is in progress to improve the accuracy including arriving at the appropriate dpi and the format. Also, in the pipeline is the generation of automated report and identifying possible diseases based on the estimated parameters.

ACKNOWLEDGMENT

We would like to thank Mr. Balamuralidhar.P for his continuous support and suggestions.

REFERENCES

[1] A. R. Gomes e Silva, H.M. de Oliveira, R.D. Lins., “Converting ECG and other paper legated biomedical maps into digital signals,” XXV Simpósio Brasileiro de Telecomunicações, Setembro 3-6, Recife –PE, Brasil.

[2] Deepthi.N, Srinivasan Jayaraman, “Fight or flight control system for drivers using ECG signal,” ICEDSP 2009, India.

[3] Fei Wang Tanveer Syeda-Mahmood David Beymer, “Information Extraction from Multimodal ECG Documents,” 10th International Conference on Document Analysis and Recognition, 2009.

[4] Guyton AC and Hall JE, Textbook of Medical Physiology, Philadelphia: Saunders, 2000.

[5] Jalel Chebil, Jamal Al-Nabulsi, Mohammed Al-Maitah, “A Novel Method for Digitizing Standard ECG Papers,” Proceedings of the International Conference on Computer and Communication Engineering, May 2008, Kuala Lampur, Malaysia.

[6] Jian-xiong Dong, Dominique Ponson, Adam Krzy˙zak, Ching Y. Suen, “Cursive word skew/slant corrections based on Radon transform,” ICDAR, September 2005.

[7] Rafael C. Gonzalez and Richard E. Woods,, “Digital Image Processing (3rd Edition)”, Prentice Hall, 2008.

[8] R. D. Lins and B. T. Ávila, “A New Algorithm for Skew Detection in Images of Documents,” Proceedings of ICIAR 2004, Lecture Notes in Computer Science, vol. 3212, pp. 234-240, Springer Verlag, 2004.

[9] Tsair Kao, Len-Jon hwang, Yui-Han Lin, Tzong-huei Lin, Chia-Hung Hsio, “Computer Analysis of Electrocardiograms from ECG paper Recordings,” Proceeding of 23rd annual EMBS international conferences, Istanbul, Turkey, 2001.