A Novel Method for ECG Paper Records Digitization

Xiaohan Sun[1], Qince Li[1], Kuanquan Wang[1], Runnan He[1], Henggui Zhang[1,2,3,4*]

[1]Harbin Institute of Technology, Harbin, China
[2]The University of Manchester, Manchester, UK
[3]Peng Cheng Laboratory, Shenzhen, China
[4]Pilot National Laboratory of Marine Science and Technology, Qingdao, China

Abstract

Most of the ECG test recordings obtained from patients in clinic is in paper records. It is difficult for efficient and automatic diagnosis of cardiac diseases based on paper ECG recordings without expert experiences. Thus, the digitization of ECG papers is of great significance for both basic research and clinical purposes. However, most of current methods extracting signals from single lead ECG images are manual, prohibiting their use for large database. This study proposed an algorithm to extract ECG signals automatically from scanned 12 lead ECG paper recordings.

The original ECG recording images were pre-processed by operations including edge detection, image binarization and skew correction. After pre-processing, ECG waveforms were extracted from background grids based on Connected Component Analysis (CCA). For waveform segmentation, horizontal projection was applied to obtain segmentation boundaries. The ECG signal trace was then traversed to extract ECG signal time series. The extracted signal was plotted by using MATLAB as final ECG signal graph.

The proposed algorithm was tested on 129 actual ECG recordings of patients. The results revealed that the extracted signals retained essential features of paper ECG recordings.

1. Introduction

Time series of ECG signals provides one of the main methods for non-invasive diagnosis of heart diseases. Over the years, most of ECG recordings were collected in the paper format, forming a challenge for data archiving to construct electronic medical record database. It also imposes limitations to further use of the data for training machine learning algorithms for automatic diagnosis of cardiac disorders. As paper ECG documents constitute a rich database of clinical information for patients with variant heart diseases, digitalization of them not only saves repository space, but also provides essential information for clinical and basic scientific research in the field of cardiac electrophysiology.

The main steps of ECG digitization include ECG image background grid detection, background grid elimination and ECG waveform extraction. For grid detection, Badilini [1] proposed three ways to identify the background grid: precise mode, range mode and manual mode. The premise of the three modes is to accurately identify the position of ECG grid lines, but the uneven color or broken lines of the background grid may have an impact on the accurate identification of the grid line positions. For background grid elimination, Mitra [2] et al. proposed to eliminate gridlines by setting a distance threshold between two interrogation points. In other studies, Prashanth [3] and Kao [4] et al. used morphological operations to remove the background grid from the ECG. Chebil [5] proposed the use of the threshold method for curve generation. Shen[6] proposed a space-oriented and frequency-oriented approach for curve extraction. For waveform extraction, most of the existing methods are for single-lead images, so multi-lead ECG needs to be segmented manually.

We proposed an automatic algorithm for 12-lead ECG digitization. The algorithm started with pre-processing operation, after that, waveforms were extracted. The extracted ECG waveforms were then classified into those of single leads. Finally, digital ECG data was extracted from ECG signal traces.

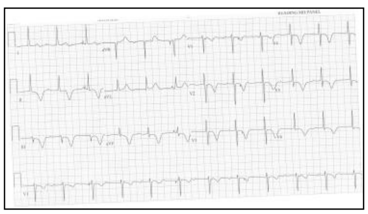
2. Method

2.1. Pre-processing

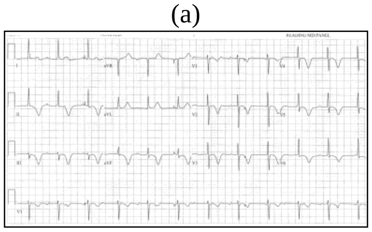
Pre-processing operations include edge detection, image binarization and skew correction. To detect the edge of binarizing area, three classical edge detection operators including Sobel operator, Canny operator and LOG operator were used to detect the edge of ECG and their

 ISSN: 2325-887X DOI: 10.22489/CinC.2019.264

detection effects were compared. By comparing the edge detection effects, we found that the Sobel operator edge-detection method was able to clearly identify the edge of the ECG curve, but the line detection effect on the background grid was not ideal. Therefore, we thought it was more suitable for edge detection of the curve. As the LOG operator edge detection could clearly identify the background grid line, it was thought to be conducive to line detection, and can be used for Hough transform line detection. For the Canny operator for edge detection, our results showed un-satisfaction for either the edge of the curve or the background grids as compared to the results with the Sobel operator and the LOG operator, so the Canny method was not implemented. In experimentation, we found that the scanned electrocardiogram image may be tilted, which has certain influence on the extraction of ECG curve. After edge detection, the ECG image was binarized. Then we used Hough transform to detect the ECG lines. The tilt angle was calculated for each detected straight line, and the skew correction was performed based on the average tilt angle to obtain a corrected image. Figure 1 shows the original ECG image and the one with skew correction.



(a)



(b)

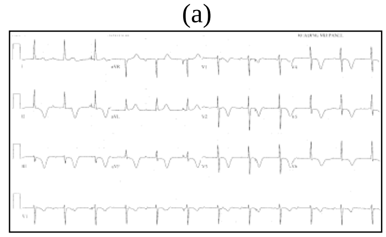
Figure 1. (a) Original skewed ECG image; (b) ECG image after skew correction.

2.2. Waveform Extraction

The waveform extraction of ECG is to separate the waveform from the background grids of the ECG image, that is, to distinguish the pixel points of the ECG waveform from the pixel points of the background grid, thereby obtaining a waveform curve.

The scan-line-seed-filling algorithm is a filling algorithm based on connected region analysis. Compared with the common boundary filling algorithm and the injection filling algorithm, the scan-line-seed-filling algorithm does not use the recursive push method to determine the neighbouring points of the seed pixels. The idea of the scan-line-seed-filling method is as followings: selecting a target pixel as a seed, and scan the specified area to fill pixel that has the same pixel value and is adjacent to the seed pixel in the left and right sides respectively. Next, it fills the upper and lower adjacent areas and repeats the process until the fill ends of the image. The pixels filled are the waveform extracted. Figure 2 shows the waveform extraction process of ECG.

(a)



(b)

Figure 2. (a) ECG image before waveform extraction; (b) ECG image after waveform extraction.

2.3. Waveform Segmentation

Since the ECG image is composed of multiple leads, in order to realize the digitization of ECG, the image should be divided into sub-images composed of a series of single waveforms, and the individual waveform images are separately processed.

Horizontal projection converts the pixel distribution features of a two-dimensional image into a one-dimensional function on the x-axis. The ECG image after curve extraction consists of white background pixels and black waveform pixels. The projection of one pixel row of an image is to take a straight line in the direction, count the number of black pixels on the image perpendicular to the line as the projection value of the pixel row. A horizontal projection of the image was obtained by displaying the projection value distribution of all the pixel rows in an image. According to the horizontal projection the segmentation coordinates of the image can be obtained, and the original image was segmented based on the coordinates to obtain sub-images containing only one waveform curve. Figure 3 shows the horizontal projection of ECG.

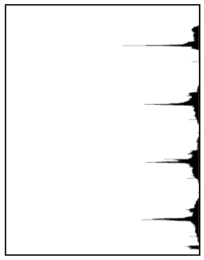


Figure 3. Horizontal projection of the ECG image.

2.4. ECG Data Extraction

ECG data extraction is a process of converting pixel information stored in an image into an ECG signal. To transfer ECG waveform curve into ECG signal, the time corresponding to each pixel of the abscissa and the number of voltages corresponding to each pixel of the ordinate need to be calculated. The time and voltage corresponding to each large grid of the ECG are fixed values, respectively 0.2s and 0.5mV, so the number of pixels in each large grid needs to be calculated to find the corresponding relationship between pixel points with time and voltage.

If the image dpi and paper speed are known, the number of pixels included in each large grid can be directly calculated. The calculation formula is as follows:

$$p_n = \frac{t[\mathrm{sec}/grid] \times v[mm/\mathrm{sec}] \times DPI}{25.4[mm/inch]} \qquad (2\text{-}1)$$

Where p_n calculates how many pixels each large grid represents; DPI is the resolution of the scanner; v is the paper feeding speed of ECG; t is the time represented by the large grid.

If the image dpi and paper speed are unknown, the number of pixels included in each large grid can be calculated from the horizontal projection of the image. Since the horizontal projection records the number of pixels included in each row, the line of the horizontal projection peak is the position of the baseline of the ECG waveform. The number of pixels in each large grid can be obtained by calculating the pixel difference between two adjacent peaks, taking the average value, and being divided by the number of cells of the two adjacent ECG waveforms.

The specific operation is: traverse the ECG waveform image by column, and record the row coordinate of the first pixel value of each column whose pixel value is 0. Then, according to the correspondence between the pixel and the time-voltage, the recorded pixel value of the curve is converted, and the curve information in the electrocardiogram is converted into the ECG signal data for storage.

3. Results

129 scanned ECG printouts were used to test the method. The extracted waveform of the single-lead signal is shown in Figure 4, while the extracted entire ECG waveform is shown in Figure 5. Results shown in Figure 4 and Figure 5 both indicates that the proposed method worked very well for extracting ECG waveforms, which are close to the ECG curve information on the ECG paper.

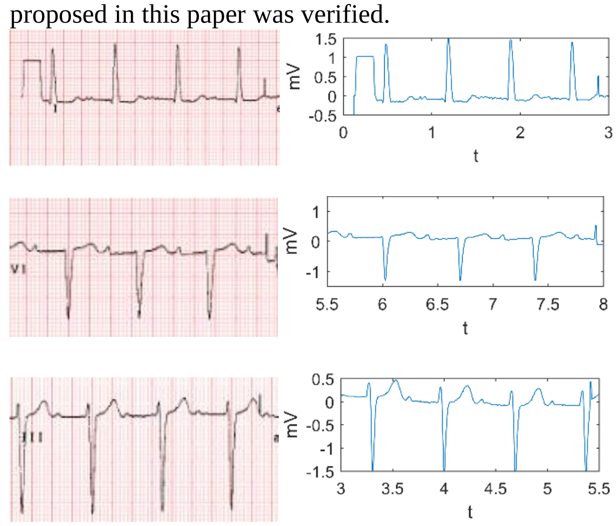
In order to quantitatively detect the effect of the ECG curve extraction algorithm, the R-R interval of the paper ECG was manually measured and compared with the R-R interval of the corresponding ECG curve obtained after digitization. The effect of curve digitization was evaluated by calculating the root mean square (RMS) and percent mean square error (PRD) of the R-R interval of the ECG signal data and the R-R interval of the original data.

The root mean square (RMS) and percent mean square error (PRD) of the RR interval of the ECG signal data extracted from the 7-group recorded paper image and the manually measured RR interval were calculated. The comparison results are shown in Table 1.

Table 1. RMS and PRD of extracted ECG data and original data RR interval.

ECG	PRD(%)	RMS(%)
1	1.86	1.21
2	3.17	2.83
3	3.44	1.58
4	1.87	1.62
5	6.85	6.34
6	1.28	0.92
7	4.93	1.12

It can be seen from Table 1 that the average of the mean square error of the RR interval obtained by comparing the RR data of the original data of the 7 sets of records and the paper data extracted by the paper version was 3.34%, and the average value of the root mean square was 2.23%. The validity of the ECG waveform extraction algorithm proposed in this paper was verified.



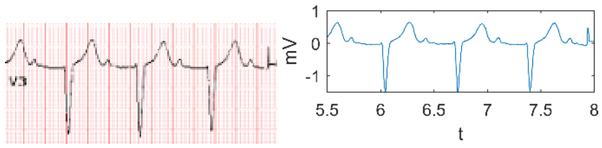
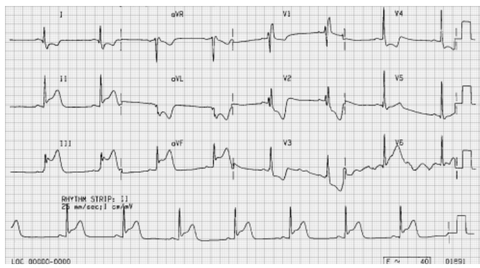
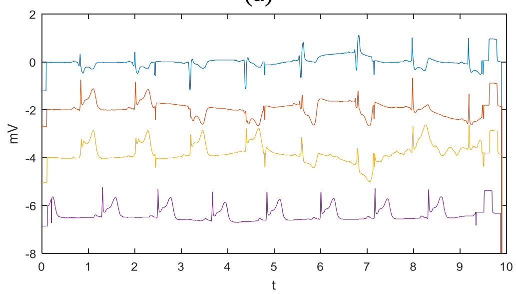


Figure 4. Extraction effect of the single ECG lead.



(a)



(b)

Figure 5. Extraction effect of the whole ECG waveform.

4. Conclusions

This study developed a novel method for signal extraction from ECG paper. Unlike previous ECG digitization algorithms, which can only extract ECG signals from single lead, this method can automatically extract ECG signals from 12 lead ECG paper. By comparing the extracted ECG waveform data with the paper ECG waveform, it was found that the extracted ECG waveform data retains the ECG information of the paper ECG. Based on current algorithm, automatic analysis and diagnosis algorithm of ECG will be further developed for computer aided diagnosis of cardiac arrhythmias.

Acknowledgments

The work is supported by the National Science Foundation of China (NSFC) under Grant Nos. 61572152 (to HZ), 61571165 (to KW), 61601143 (to QL) and 81770328 (to QL), and China Postdoctoral Science Foundation under Grant Nos. 2015M581448 (to QL).

References

[1] Badilini. F, Erdem. T, Zareba. W, & Moss. A, “Ecgscan: a method for conversion of paper electrocardiographic printouts to digital electrocardiographic files,” *J. Journal of Electrocardiology*, vol. 38, no. 4, pp. 310-318, 2008.

[2] Mitra Sucharita,Mitra M, Chaudhuri B B, “Generation of digital time database from paper ECG records and Fourier transform-based analysis for disease identification.,” *J. Computers in Biology and Medicine*, vol. 34, no. 7, 2004.

[3] Swamy P, Jayaraman S, Chandra M G, et al, “Animproved method for digital time series signal generation from scanned ECG records,” C. *International Conference on Bioinformatics & Biomedical Technology. IEEE*, 2010.

[4] Kao T, Hwang L J, Lin Y H, et al, “Computer analysis of the electrocardiograms from ECG paper recordings,” C. International Conference of the IEEE Engineering in Medicine & Biology Society. IEEE, 2001.

[5] Chebil J, Al-Nabulsi J, Al-Maitah M. “A novel method for digitizing standard ECG papers,” C. International Conference on Computer & Communication Engineering. 2008.

[6] Shen T W, Laio T F. “Image processing on ECG chart for ECG signal recovery,” *J. Computers in Cardiology*, 2009, 36: 725-728. no. 36, pp. 725-728, 2009.

Address for correspondence:

Henggui Zhang.
92 West Dazhi Street, Nangang District, Harbin, China
henggui.zhang@manchester.ac.uk