ECG Waveform data Extraction from Paper ECG Recordings by K-means Method

Guojie Shi, Gang Zheng, Min Dai

Tianjin University of Technology, Tianjin, China

Abstract

Though modern ECG machine with digital-out has been applied for years, paper recordings are still chosen by medical organizations especially in China. But the recording paper is easily broken. These ECG data were necessarily to be extracted and keep the valuable ECG information as digital type for clinical information sharing, online diagnosing and ECG database establishing. A method based on K-means was proposed to extract ECG data from paper recordings. The ECG waveform and the background grid were separated well.105 patients' ECG paper recordings were adopted in the experiment. And the recordings are in different damage level, the paper are in different background color and made by different manufacturers. The result shows that ECG waveform can be extracted precisely and smoothly. The precision rate of RR interval, QRS interval, QT interval, ST slope, and R amplitude from ECG data which are digitalized by the approach in the paper could reach 99%.

1. Introduction

To solve the problem of easily broken of the ECG papers, many related works have been started at home and aboard [1-4]. In order to extract the waveform fast and precisely, improved k-means based on Sobel is proposed in the paper. The method proposed doesn't cost too much time as snake method [1], which result heavily rely on the initial contour. Instead of gray image, the color image use in the paper contains more information, which will lead to high precision. Beside this, the improve k-means method needn't have to mark the starting point of the waveform manually [2-4].

2. Extraction of clustering feature

The scanned ECG is composed by waveform, background grids, edge and noise. The aim for feature extraction is to find the characterisc value which will reflect the difference between them. Color feature is the most important to distinguish between ECG waveform and background. Besides, gradient value can help to distinguish edge from background because edge and noise usually has big gradient value.

2.1. Extraction of color feature

Color feature is the most extensive visual characteristic in the image segmentation. The Lab space is used for its broad color gamut and most similar to human vision. The Lab space is opposite-color space, L said brightness, a and b said color opposition dimension. Even change in L*a*b model corresponds to even change in color perception, so any difference between two color in lab can be approximated to a point in three dimension as (L,a,b).

2.2. Extraction of gratitude feature

Edge and noise usually mean big changes among pixels which can be marked by gratitude value. The gratitude value in background and objective internal are usually small, while edge and noise have large correspondence value. And the gratitude in the paper is expressed as G.

All the extracting features reflect the differences between ECG waveform, background, edge and noise. Then any sample pixel used in k-means clustering can be expressed as (L,a,b,G).

3. Improved k-means used to extract the ECG waveform

3.1. Introduction of k-means

K-means is used in the paper as the core of the ECG waveform extraction method. The basic idea of this unsupervised method is given. First, making the clustering number initialized and the iteration convergence expression for measurement function is given. Then, k initial clustering center is randomly selected. Along to the distance measurement, each object will be assigned to the nearest center, and the new clustering center will be got by computing the average in each class. The iteration will be repeated until the clustering center no longer changed or iteration times used up. K-means results show that the similarity in one class is highest, while lowest similarity between classes.

The clustering result of traditional k-means will lead to different results each time because the value of k is usually based on experience, and the center is set randomly[5,6]. Besides, the iteration cost too much time result in low efficiency. Considering large quantity data of color images, the method with small calculation should be considered.

Two problems will caused if traditional k-means was used to extract the waveform, as:

(1)The amount of data is too high will cost much time.

(2)The initial clustering center and the number of categories directly affect the efficiency and accuracy.

Then the improved k-means is proposed considering the above problems and demand in actual research. Gratitude operator is used in the method to reduce the clustering samples because ECG waveform is border on the background which will lead to high gratitude value. Only step-like edge-point set {G(x,y)} is kept after that. {G(x,y)} contains upper boarder points, lower border points and noise. Then the close operation is used to fill the waveform hole and the clustering sample set {K(x,y)} will finally got.

3.2. Sobel operator is used to decrease clustering sample size

The edge is the most import basis in the paper because it mark the pixel set which have great changes in gray value can tell difference between object, background and region. The gratitude operator can detect the edge because the gratitude value at edge is usually high. The noise will also be involved into the edge set because the gratitude value of noise is high too.

Sobel operator is used to detect the edge by computing on the left and right pixel or top and down pixel weighed and averaged, then the extreme value could be got at edge with low time complexit. Sobel operator can not only extract the edge and also restrain the noise.

The definition of sobel operator is as below:

$$G_x = [f(x+1, y-1) - f(x-1, y-1)] + 2[f(x+1, y) - f(x-1, y)] + [f(x+1, y+1) - f(x-1, y+1)] \quad (1)$$

$$G_y = [f(x-1, y+1) - f(x-1, y-1)] + 2[f(x, y+1) - f(x, y-1)] + [f(x+1, y+1) - f(x+1, y-1)] \quad (2)$$

$$\nabla f = \sqrt{G_x^{\ 2} + G_y^{\ 2}} \quad (3)$$

Where, Gx detect the horizontal edge, Gy detect the vertical edge.

The gradient image G(x,y) will be got after image f(x,y) computing with equation (1) (2). Each point p(x,y) in G(x,y) will be compared with Th. Each point p(x,y) is step-like edge point if p(x,y)> Th, and all step-like points form the step-like edge set {G(x,y)}.

3.3. Closed operation is used to fill the waveform hole

The mathematical morphology is a nonlinear filtering method. First, the structuring element is selected according to original image target feature. Then, translation, intersecdtion, and Union is used to work on the original image respectively with the structuring element. The morphology operator will not enhance or amplifier noise though it is sensitive with noise.

The given binary image is A, and the structuring element is B, then the equation of the closed operation is :

$$A \bullet B = (A \oplus B) \Theta B \quad (4)$$

The closed operation can fill the hole in the image by dilating first and then eroding. The whole between upper border and lower border can be filled when {G(x,y)} is worked with the closed operation. Figure 1 shows the partial result of {G(x,y)} after image f(x,y) is worked with sobel operator. Figure 2 shows the partial result of {K(x,y)} after {G(x,y)} is worked with the closed operator. Figure 3 shows the gray histogram of f(x,y). Figure 4 shows the gray histogram of {K(x,y)}.

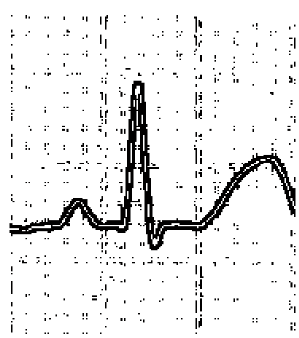

Figure 1. Partial result of {G(x,y)}.

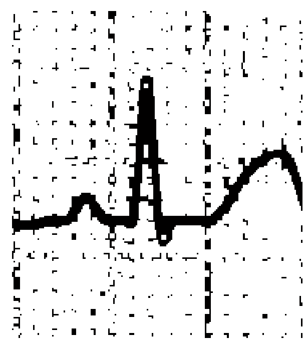

Figure 2. Partial result of {K(x,y)}.

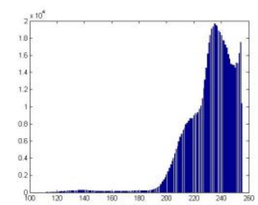

Figure 3. Histogram of f(x,y).

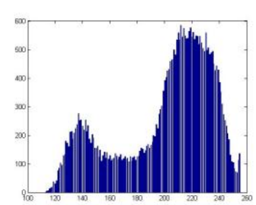

Figure 4. Histogram of {K(x,y)}.

From Figure 3, the distribution of the pixels is extremely uneven, and the wave trough is not apparent. The gray value distribution of the waveform to be extracted arranges from 120 to 160, but it is difficult to judge its specific distribution because small proportion of the whole image.

The method proposed in the paper can solve this problem. Most irrelevant pixel samples have been filtered after the original image has been worked by sobel operator and closed operator. As figure 4 shows, the pixel samples used by k-means have been greatly reduced.

3.4. Extraction of the ECG waveform

The scanned ECG image usually contains waveform, background grid, edge and noise. The aim of the k-means clustering is to cluster the pixels belong to the waveform into the same category. The following (1) expresses how to determine the initial clustering center, and then cluster by distance measurement with other pixel samplers using (L,a,b,G) as clustering features.

(1)Determining the initial clustering center

The gathering of the pixels can be largely reflected by the grayscale histogram which shows the frequency of pixels at each grayscale. As figure 4 shows, n peaks of the histogram are chosen as initial clustering centers, and n is the number of clustering categories. So all pixels of the loop computations between into pixels and a few peaks, which will reduce the comparison between the search process, greatly reduce the computation cost.

(2)Computing the features of the initial clustering center

The features of the initial clustering center can be calculated with the original color image according to the peaks in the histogram.

(3)Extracting the waveform by k-means method

The clustering can be started by computing the distance between pixels and centers when initial centers are determined and their features have been computed.

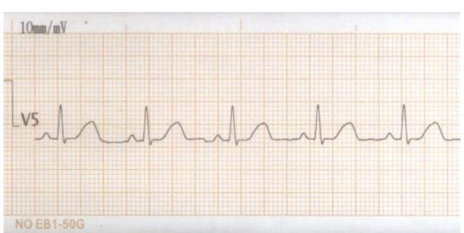

Figure 5. Image of f(x,y).

3.5. Algorithm for improved k-means method

The image used in the paper is shown in figure 5, and figure 6 shows the extracted waveform, figure 7 shows the restricted waveform and background grid.

Step one: initialize T_h, B, {G(x,y)}= ϕ ,{K(x,y)}= ϕ .

Step two: according to equation (1)(2)(3), get gradient image G(x,y). For each p(x,y) $\in$ G(x,y), if p(x,y)> T_h, then {G(x,y)}= {G(x,y)}+p(x,y).

Step three: according to equation (4), get clustering set {K(x,y)} by using closed operator working on{G(x,y)}. $\{K(x,y)\} = (\{G(x,y)\} \oplus B)\Theta B$.

Step four: according to the histogram of {K(x,y)}, determine the initial clustering center z1,z2,…zn.

Step five: according to the distance measurement, assign each pixel sample to the nearest categories.

Step six: return to step two if there are other pixels need to be clustered, or over if no other pixels.

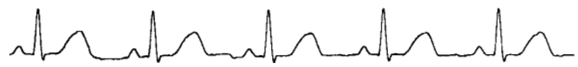

Figure 6. ECG waveform after extraction.

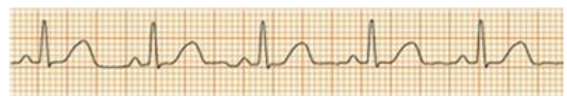

Figure 7. Restructed ECG waveform and background grid.

4. Experiments and conclusion

105 patients' ECG paper recordings were adopted in the experiment. The data were obtained from different level of medical services organization. The date of these recordings is ranging from 1990s to present. And the recordings are in different damage level, the paper are in different background color and made by different manufacturers.

After that, evaluation between the original paper ECG and extracted ECG is given. The R wave amplitude, heart rate and RR interval are compared in this experiment. Due to different operations on each printout, every sample has its own number of R waves. And the R wave amplitude is measured according to the initial of the QRS. Part of the result is shown in table 1, where W_{oi} said original waveform, W_{di} said extracted waveform, E_i said the absolute error between W_{oi} and W_{di}.

$$E_i = |W_{oi} - W_{di}| / W_{oi} \quad (5)$$

ECG sample	data	Slant angle	R1 (mv)	R2 (mv)	R3 (mv)	R4 (mv)	R5 (mv)	RR intervals (s)
	W_{o1}		1.70	1.75	1.70	1.75	Null	0.90
ECG1	W_{d1}	5.28°	1.68	1.75	1.72	1.76	Null	0.91
	E_1		0.01	0	0.01	0	Null	0.01
	W_{o2}		1.70	1.73	1.65	Null	Null	0.92
ECG2	W_{d2}	7.44°	1.72	1.71	1.67	Null	Null	0.92
	E_2		0.01	0.01	0.01	Null	Null	0

	W_{o3}		1.50	1.48	1.45	Null	Null	0.80
ECG3	W_{d3}	6.71°	1.49	1.47	1.46	Null	Null	0.81
	E_3		0	0	0	Null	Null	0.01
	W_{o4}		1.71	1.70	1.65	1.64	Null	0.91
ECG4	W_{d4}	9.39°	1.73	1.71	1.67	1.65	Null	0.92
	E_4		0.01	0	0.01	0	Null	0.01
	W_{o5}		1.80	1.75	1.75	1.78	1.79	0.70
ECG5	W_{d5}	-7.19°	1.79	1.78	1.75	1.79	1.79	0.71
	E_5		0	0.01	0	0	0	0.01
	W_{o6}		1.50	1.55	1.53	1.53	1.51	0.75
ECG6	W_{d6}	5.79°	1.52	1.54	1.53	1.54	1.51	0.76
	E_6		0.01	0	0	0	0	0.01
	W_{o7}		1.60	1.58	1.56	Null	Null	0.62
ECG7	W_{d7}	-7.78°	1.59	1.58	1.57	Null	Null	0.61
	E_7		0	0	0	Null	Null	0.01
	W_{o8}		1.79	1.73	1.70	1.80	Null	0.97
ECG8	W_{d8}	7.70°	1.78	1.71	1.69	1.78	Null	0.98
	E_8		0	0.01	0	0.01	Null	0.01
	W_{o9}		1.56	1.56	1.55	1.53	Null	0.76
ECG9	W_{d9}	6.60°	1.57	1.57	1.55	1.53	Null	0.76
	E_9		0	0	0	0	Null	0
	W_{o10}		1.61	1.61	1.68	1.62	Null	0.95
ECG 10	W_{d10}	0.5°	1.6	1.61	1.68	1.61	Null	0.96
	E_{10}		0	0	0	0	Null	0.01

Table 1. part of the results.

From Table 1, the heart rate and RR interval after digitization have small differences from the original paper ECG. The experiment shows the accuracy rate of waveform amplitude 99%, and heart rate of that 99%.

Experiment shows good results with high accuracy 99%. The results satisfied the clinical requirements, and can be used for network medical service.

Acknowledgements

The paper was supported by Tianjin Natural Science Foundation (10JCYBJC00700) and Tianjin Key Foundation on Science Supporting Plan (10ZCKFSF00800).

References

[1] Badilini F, Erdem T. Method and System for Converting Paper ECG Printouts to Digital ECG Files, United States Patent Application Publication, US2005/0027201 A1. 2005; 2.

[2] Prashanth S, Srinivasan J, M.Girish C. An Improved Method for Digital Time Series Signal Generation from Scanned ECG Records. 2010; 400-403.

[3] Morales E, Sevilla D, Pierluissi J. Digitization and Synchronization Method for Electrocardiogram Printouts. 2005; 1588-1591.

[4] Janel C, Jamal AN, Mohammed AM. A Novel Method for Digitizing Standard ECG Papers. 2008; 1308-1312.

[5] LI G, WAGN ZY, HOU ZQ. Color image segmentation algorithm based on k-means clustering and region merging. Journal of Computer Apppication, 2010; 30:354-357.

[6] Tse WC, Chen YL, ShaoYC. Fast Image Segmentation Based on K-Means Clustering with Histograms in HSV Color Space. Multimedia Signal Processing, IEEE 10th Workshop, Oct. 2008; 322-325.

Address for correspondence:

Dr Gang Zheng
Tianjin University of Technology, Tianjin, China.
Email: Kenneth_zheng@vip.163.com