ONE-DIMENSIONAL SIGNAL EXTRACTION OF PAPER-WRITTEN ECG IMAGE AND ITS ARCHIVING

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ABSTRACT

A method for converting paper-written electrocardiograms to one dimensional (1-D) signals for archival storage on floppy disk is presented here. Appropriate image processing techniques were employed to remove the background noise inherent to ECG recorder charts and to reconstruct the ECG waveform. The entire process consists of (1) digitization of paper-written ECGs with an image processing system via a TV camera; (2) image preprocessing, including histogram filtering and binary image generation; (3) ECG feature extraction and ECG wave tracing, and (4) transmission of the processed ECG data to IBM-PC compatible floppy disks for storage and retrieval. The algorithms employed here may also be used in the recognition of paper-written EEG or EMG and may be useful in robotic vision.

1. INTRODUCTION

There is a large accumulation of paper-written ECG charts in many hospitals in China. These charts are not only hard to preserve but also difficult to retrieve. It was our goal to design an algorithm to convert the two-dimensional (2-D) paper-written ECG information to 1-D data and build a system for archiving these data.

The entire process is realized via an M75 image system made by IIS Corporation with a VAX 11/730 as its host computer. An ECG chart is scanned by a Dage 68 TV camera and digitized to form a 512x512 image with 8 bits per pixel of grey scale. Each camera image is fixed to include exactly four QRS complexes per frame. Consequently, the duration of the ECG wave varies from frame to frame. In section 4, the time calibration of these signals is discussed.

The purpose of preprocessing is to eliminate noise. For this application, noise includes shadows caused by non-uniform illumination, the grid-pattern background inherent to ECG recording paper, and random grey value changes in the image. Standard threshold techniques can be applied to the digitized images to suppress unwanted noise.

Signal extraction consists of the following three processes, (1) location of the R-peaks (described in section 3), (2) determination of the slowly-varying portion of the ECG wave (described in section 5), and (3) detection of the QRS complex (described in section 6). Features are extracted using template matching and neighborhood tracing techniques.

A block diagram of the entire procedure is shown in figure 1.

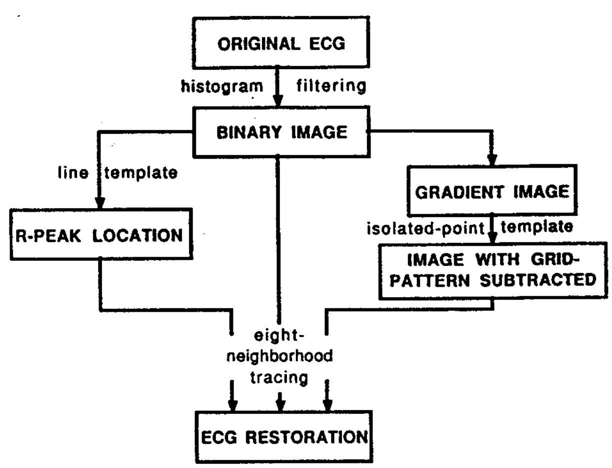

FIGURE 1. BLOCK DIAGRAM OF ECG IMAGE PROCESSING

We believe that the procedures described below completely solve the problem of ECG signal compression from 2-D to 1-D. These procedures can also be used in the analysis of EEG, EMG and other kinds of paper-written single-valued signals.

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2. PREPROCESSING OF AN ECG IMAGE

The first step of preprocessing is to select a proper grey value as a threshold to separate the ECG signal from image noise. Grey levels below and above this threshold are set to 2 (white) and 0 (grey), respectively. This forms an image with 1-bit of grey scale in each pixel, and effectively suppresses noise while leaving the ECG signal undistorted.

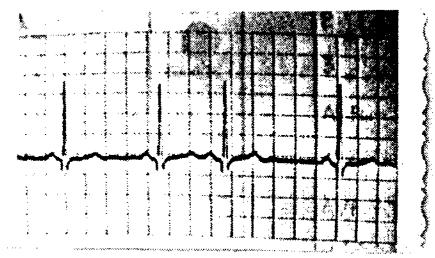

FIGURE 2. ORIGINAL IMAGE

Figure 2 is a sample of a digitized ECG image. A histogram of grey values from this image is shown in figure 3. We attribute the two peaks in the histogram to the

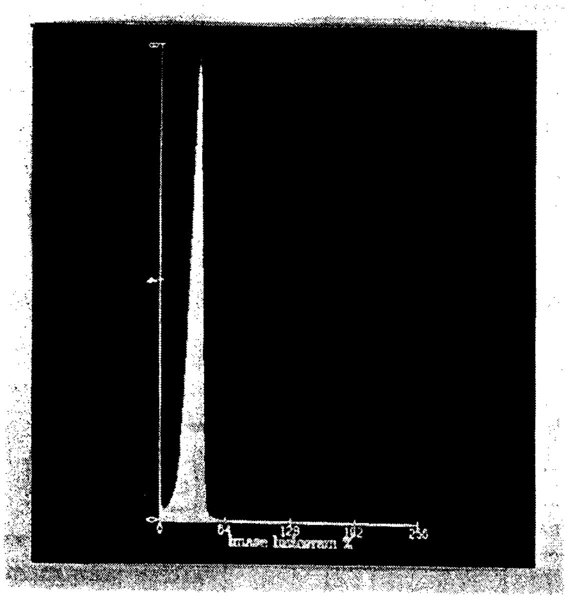

FIGURE 3. HISTOGRAM OF FIGURE 2

ECG signal (the small first peak centered near zero) and to noise (the prominent second peak centered at ~ 40). A grey value between these peaks is chosen as the threshold for binary image formation. Filtering is performed on the histogram before threshold calculation to smooth random minima in the histogram. The binary image resulting from the ECG trace in figure 2 is shown in figure 4.

3. R-PEAK FEATURE EXTRACTION USING TEMPLATE MATCHING

A line template is used to locate R-peaks. The loca-

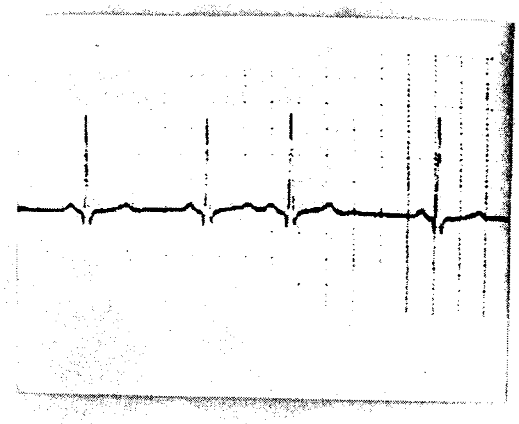

FIGURE 4. BINARY IMAGE

tions of R-peaks are very important in ECG analysis and they are often difficult to detect. After careful examination of various R-peaks, we selected a 20x1 vertical line template, as shown in figure 5. Every cell represents a

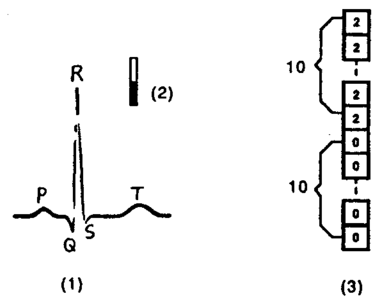

FIGURE 5. (1) QRS COMPLEX
(2) LINE-TEMPLATE (IMAGE)
(3) 20X1 LINE-TEMPLATE MATRIX

pixel. The value associated with each cell represents the grey scale of the pixel. Our decision threshold for a match between the template and the image was chosen to be 19 (20 is the theoretical value for a full match). We are confident that this decision threshold of 19 insures that all R-peaks are detected.

4. GRID-PATTERN ELIMINATION

The binary image (example in figure 4) is not yet suitable for ECG wave extraction. Two characteristics of the binary image are problematic. First, the QRS complex is not continuous and secondly, the grid-pattern background may lead the tracing algorithm on a stray course. This section describes the procedures used to overcome the second problem, the presence of the grid-pattern background.

A gradient transformation which does edge-detection is applied to the binary image along the Y-axis. The result-

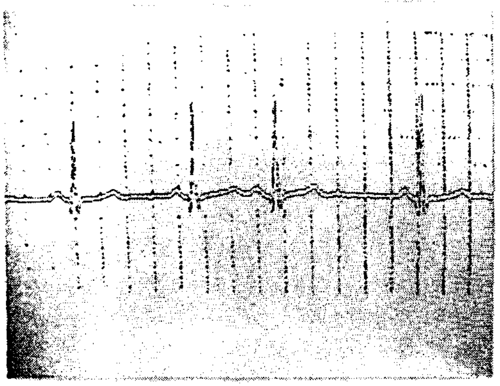

FIGURE 6. GRADIENT IMAGE

ing image after gradient transformation is shown in figure 6. We find that the former solid lines of the grid-pattern are converted to many isolated points and are easily distinguished from the ECG wave contours. Figure 7 illustrates the effect of the edge-detector gradient transformation on a typical ECG segment and on an isolated point. Figure

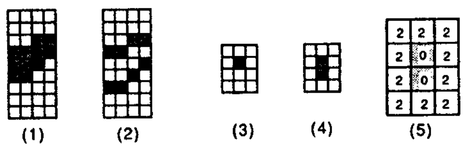

FIGURE 7. ISOLATED-POINT TEMPLATE

(1) ECG segment before gradient transformation
(2) ECG segment after gradient transformation
(3) "Isolated-point" before gradient transformation
(4) "Isolated-point" after gradient transofrmraiotn
(5) grey-scale matrix corresponding to (4)

7(5) shows the isolated-point template used to detect isolated points on gradient image.

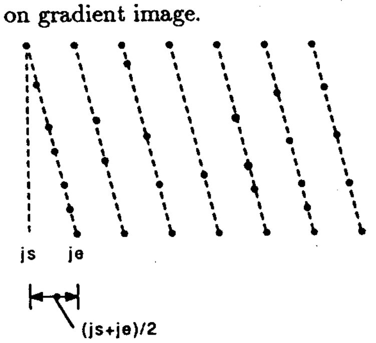

FIGURE 8. A SKETCH FOR VERTICAL GRID LINES
(THE SLOPE HAS BEEN EXAGGERATED)

Since the spacing of the grid-pattern is regular (see figures 2 and 8), we only need to detect a few vertical grid lines (in this case, seven vertical lines are detected). Our algorithms take advantage of the fact that the grid-pattern is not perfectly aligned with the Y-axis of the pixel pattern. Thus the digitized grid-pattern appears slanted. For each vertial grid line, we take the start point (js) and the end point (je), and calculate the arithmetic average (js+je)/2. The mean spacing of these seven lines is computed. Given this mean spacing, the locations of rest of the lines can be predicted. Finally, an image (figure 9) is generated with the predicted grid-pattern subtracted from the gradient transformed image. The mean spacing of grid lines can also be used as a ruler to measure the heart-rate, R-R interval and QRS complex width.

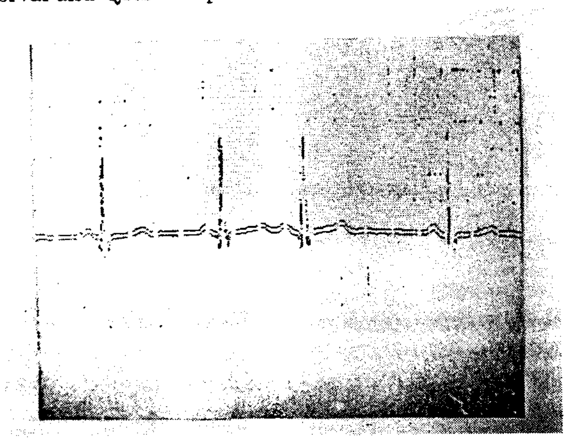

FIGURE 9. IMAGE WITH GRID-PATTERN SUBTRACTED

5. EIGHT-NEIGHBORHOOD TRACING

The idea of eight-neighborhood tracing has its roots in connectivity theory. Given a pixel in a continuous single-valued wave, then one of its eight neighboring pixels must be located on this wave also. Except for the QRS complexes where discontinuities may occur (see section 6), the rest of the ECG wave is continuous and single-valued.

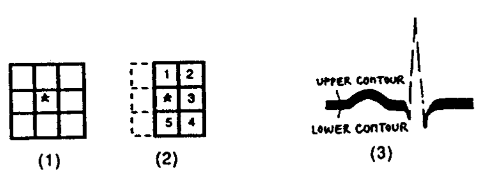

FIGURE 10. EIGHT-NEIGHBORHOOD TRACING
(UPPER EDGE TRACING)

Figure 10 illustrates the tracing pattern of the eight-neighborhood tracing method. The $\star$ denotes the pixel where the current contour point is located. Numbers within the cells indicate the order in which the pixels are examined. The first pixel to be classified as belonging to the contour is taken as the true next contour point. (This procedure is similar to that of Zamperoni, 1982.) We perform eight-neighborhood contour tracing on the upper edge and on the lower edge of the ECG wave in the binary image. To accomodate discontinuities, tracing was performed in both directions, from left to right and right to left.

6. QRS RECONSTRUCTION

As mentioned above, there are discontinuities in the QRS complex waveform contour. Tracing is interrupted at these points. To restore the QRS compelx, we first find the starting point of a QRS complex by contour tracing from left to right (js, see figure 11). Secondly, we skip

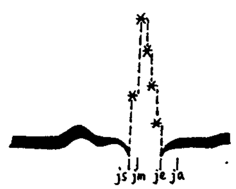

FIGURE 11. QRS RECONSTRUCTION

enough horizontal distance to reach a point on the continuous part of the ECG wave (represented by ja in figure 11) and continue contour tracing from right to left until we arrive at the end point of the QRS complex (je). We get the reconstructed ECG wave shown in figure 12 by inter-

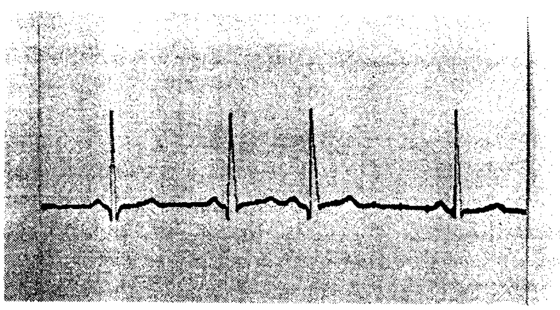

FIGURE 12. RESTORED ECG

polating between the previously detected R-peaks (jm in figure 11) and the end points of the QRS complex (js and je). The dashed lines in the figure indicate the interpolated segments.

7. SUMMARY

The final restored ECG is shown in figure12.The reconstructed ECG wave retains many key features such as the amplitude of the QRS peaks, the QRS width and the R-R intervals. A comparison of the original ECG images and their reconstructed counterparts illustrates the accuracy of the reconstruction. Our procedure converts 2-D paper-written ECG images to 1-D digitized signals. This enables convenient storage and retrieval of a large database of ECG waves.

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