ECG Print-out Features Extraction Using Spatial-Oriented Image Processing Techniques

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***Abstract*— Analyzing cardiovascular activity of patients using ECG clinical paper printouts requires prior knowledge and practice. This research used spatial-oriented image processing methods for analyzing ECG readings by retrieving only the essential features, and not all ECG data, to assist physicians in diagnosis. Different values such as Atrial (rate/min) and Ventricular (rate/min), QRS interval (sec), QT interval (sec), QTc (sec), and PR interval (sec) were successfully extracted with indication as to whether the values are within the accepted normal values, given the patient's gender and age. Performance of the system was tested based on accuracy, RMSE and normalized RMSE. The methodology achieved average accuracy as high as 95.424 % while the PR interval feature extraction achieved a relatively low average accuracy of 87.196%.**

***Index Terms*—Electrocardiogram Printout; ECG Image Processing; ECG Feature Extraction; Spatial-Oriented Image Processing.**

I. Introduction

Electrocardiogram (ECG) signal is a one-dimensional signal which records the variation of bioelectric activity with respect to time. ECG carries valuable information about the functional parts of the heart and cardiovascular system [1]. ECG (Electrocardiogram) machines record these electrical actions from the muscles of the heart and produces ECG paper printouts as output. These ECG paper printouts are in turn analyzed by health care professionals to help them monitor a patient's condition and detect abnormalities for diagnosis of not only cardiovascular diseases [1] but other related diseases [2-4].

II. Literature Review

Analyzing cardiovascular activity using ECG strips under abnormal heart beat can only be done with prior knowledge. It is considered as a very significant task to the medical experts but a complicated one to novice medical practitioners [1]. In fact, according to studies done by Noronha, R. [5], only a number of medical practitioners can accurately read ECG printouts, particularly the QT interval, which is one of the most important features of ECG. According to Moore [6], ECG interpretation skills, both in general practice and also in hospital are highly variable, and are often extremely poor. One of the possible approaches suggested by Moore to alleviate this problem of incompetence in ECG reading is the use of computers in ECG interpretation.

Image processing techniques have been used for medical informatics. Imaging processing techniques are used for enhancement and identification of the locations of diseases on CT [7], MRI [8] and other medical images. There are however limited researches [9-12] which focus on the reconstruction of ECG signals and on the extraction of important ECG information from clinical ECG paper image strips. In this research, not all ECG data are retrieved, as what have been done in other prior researches [10-11]. Only essential features were extracted as the images were analyzed in this particular study. Moreover, these researches mentioned also did not include indication whether extracted ECG information are within the normal limits given the patient's age and gender as a means of a decision support system.

III. Objectives

This research developed image processing methods to analyze ECG readings by extracting essential features of ECG strips. By using image processing techniques, the input ECG strip images were analyzed using MATLAB and produced significant ECG values such as Atrial (rate/min) and Ventricular (rate/min), QRS interval (sec), QT interval (sec), QTc (sec), and PR interval (sec). A graphical user interface was also created to detect whether the extracted values are within the accepted normal values, given the patient's gender and age. Basis for the classification of normal values is determined from the study entitled "Normal Values of the Electrocardiogram for Ages 16-90 years" conducted by Rijnbeek, P et.al [16]. Performance of the system was tested based on accuracy, root-mean-square error (RMSE), and normalized root-mean-square error (NRMSE).

IV. Research Methodology

A. Experiment Database

In testing the functionality of the methods, actual samples from different patients were used in this study. The experiment database consisted of 15 random ten-second-ECG recordings of eight (8) male and seven (7) female Filipino patients whose ages range from 24 to 77. ECG paper printouts were scanned with a resolution of 300 dots per inch (dpi) and saved in Joint Photographic Experts Group (JPG) format.

B. ECG processing

There are four main stages in the ECG processing of this research as seen in Figure 1: 1) Pre-processing, 2) Feature Extraction, 3) Classification, and 4) RMSE & percent error analysis.

Pre-processing prepared the scanned ECG image to good quality for feature extractions of amplitudes and time intervals. Classification in this research determined whether the measured ECG readings are within normal limits, given the age and gender of the patient. RMSE, NRMSE and percent errors were then computed to evaluate the methods used.

Many complex algorithms have been developed for feature extraction along with pre-processing and classification using multiple techniques [9-12]. Retrieval techniques using image processing may be divided into two: spatial and frequency feature extraction [11]. This research adopted spatial-oriented methods.

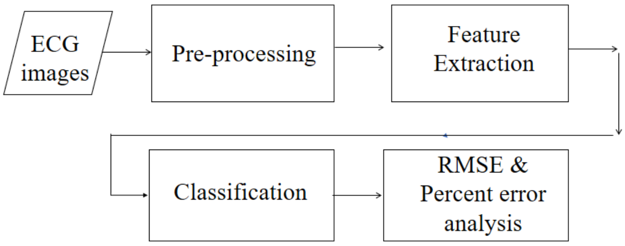


Figure 1: Main stages of ECG printout processing

C. ECG Image Pre-processing

Pre-processing as seen in Figure 2 included gray scale conversion to convert the black ECG print and the green paper grid to more coherent colors of black, white and gray. Image cropping was utilized to choose the portion of the image which was needed for analysis. Next was the enhancement of the contrast of the image and with the help of histogram equalization. Noises on the image were minimized using Median filtering. The next procedure involved image binarization with threshold selection but noise brought by unwanted ECG printout gridlines still appeared. Area opening was also applied to the binary image to further eliminate the unwanted gridlines. This procedure which was applied in this research removed from the binary ECG image all connected components or objects containing fewer than 100 pixels. An example is shown in Figure 3(a) where 20 pixels were found to be in the selected pixel region shown in Figure 3(b) of the sampled ECG image. These connected components were removed using area opening.

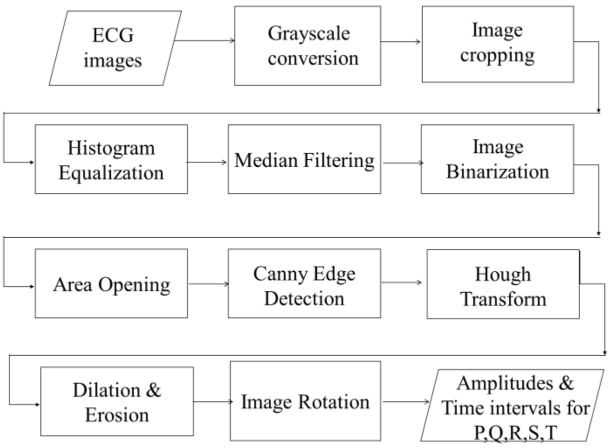


Figure 2: Image processing techniques used

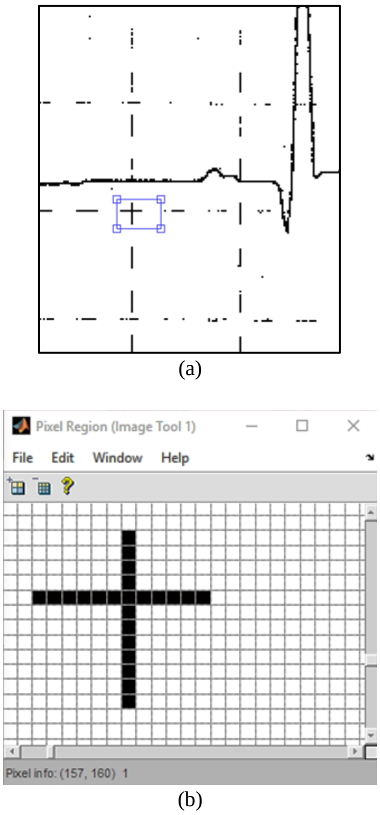


Figure 3: (a) ECG image with chosen pixel region in blue (b) Using Pixel region tool of MATLAB, the selected connected pixels were found to be 20 pixels

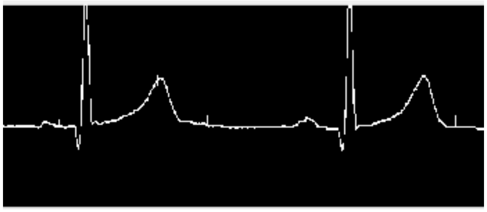


Figure 4: Binarized sampled ECG image with gridlines removed

Figure 4 shows an example of a binarized image with gridlines already removed. The missing pixels were replenished by checking the value of the neighbor pixel after dilation.

After ECG image pre-processing, only essential features of the ECG covered in this research were extracted as the images were analyzed. It can be seen from the Figure 5 that the ECG results have different points of analysis. The method presented here extracted essential ECG values such as Atrial (rate/min) and Ventricular (rate/min), QRS interval (sec), QT interval (sec), QTc (sec), and PR interval (sec). Atrial (rate/min) is heart rate based on P wave repetitions or PP intervals while Ventricular (rate/min) is heart rate measure based on R peaks or RR intervals. The P wave is an atrial contraction of small size and low-amplitude. The QRS complex looks at the ventricles and the T wave evaluates the recovery stage of the ventricles while they are refilling with blood. The time it takes from the beginning of the P wave to the beginning of the QRS complex is measured by the PR interval. The QRS interval measures electrical travel time through the ventricles and the QT interval measures ventricular depolarization and repolarization [13]. In this research, QTc calculations used Bazett's formula shown in Equation (1).

$$QTc = \frac{QT}{\sqrt{RR}} \qquad (1)$$

where: QTc= QTc in seconds,
QT=QT interval in seconds
RR=RR peaks interval in seconds

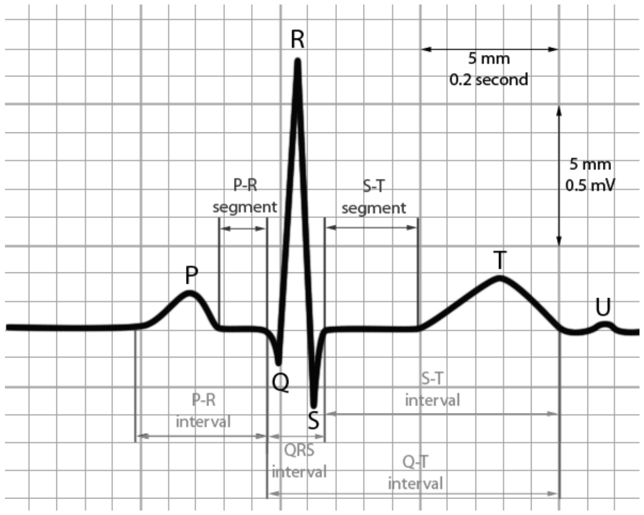


Figure 5: Typical ECG result and their points of analysis [14]

The scanned ECG image features were extracted by peak detection, time detection and analysis of shape features focused on detecting lines. Essential features and time boundaries were marked, followed by distance calculation. Edge detection using Canny's method was utilized while Hough transform was used to detect lines. The Canny method differs from the other edge-detection methods in the sense that it uses two different thresholds to detect strong and weak edges, and includes the weak edges in the output only if they are connected to strong edges [15].

Standard Hough Transform (SHT) was used to detect lines using the parametric representation of a line described in Equation (2).

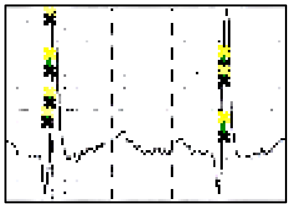
$$\rho(rho) = x\cos\Theta + y\sin\Theta \qquad (2)$$

where: ρ(rho) = distance from the origin to the line along a vector perpendicular to the line
Θ = theta is the angle between the x-axis and this vector

The Hough transforms generated a parameter space matrix whose rows and columns corresponded to these rho and theta values, respectively. Peak values in the parameter space represented potential line segment endpoints. Horizontal lines served as basis for time detection, while vertical or steep slope lines served as basis for peak detection.

Morphological operation erosion was performed first on the sampled binary ECG image before the detection of vertical lines or steep slope lines as shown in Figure 6(a). This ensured that only binary pixel comprising the target lines were left for processing as can be seen in Figure 6(b).

(a)



(b)

Figure 6: (a) Eroded Binary ECG signal (b) plot of lines derived from Hough Transforms

Apparently, as shown in Figure 7, end points of these lines derived from Hough transforms provided the location of R peaks. Line segments determined in this procedure are those lines whose thetas were near zero degrees value as shown in Figure 8. RR intervals were computed at a sampled time interval of ECG image by subtracting the position of two consecutive R peaks.

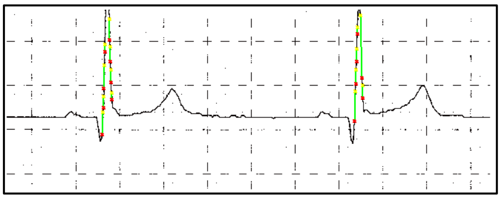


Figure 7. Plot of lines of at the QRS interval of an ECG image identified through Hough transforms

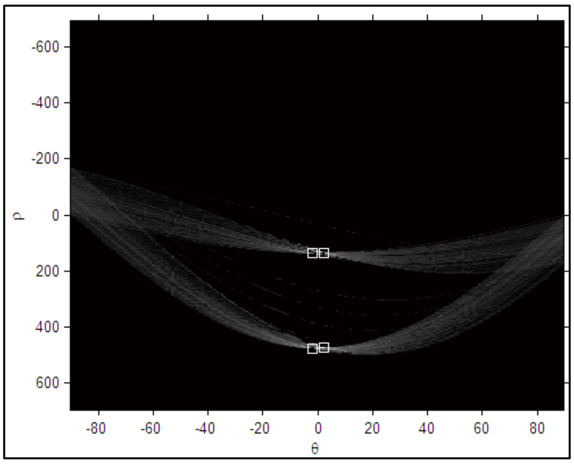


Figure 8: Plot of ρ (rho) vs. Θ (theta) of the evaluation of Hough transforms. Shown in white box the relevant horizontal lines whose theta near to zero degrees.

On the other hand, morphological operation dilation aided in determination of essential horizontal lines as shown in Figure 9 below. Determination of horizontal lines based on Hough transforms depended on the smoothness of the ECG signal to be sampled. ECG signals with unwanted high frequency harmonics were filtered first before Hough Transforms was applied. Peak values of ρ (rho) vs. Θ (theta) determined the possible endpoints of horizontal lines as seen in Figure 10.

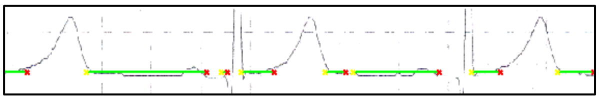


Figure 9: Plot of lines of theta equal to -180 and 180 degrees in an ECG image identified through Hough transforms after dilation

As shown in Figure 9, the end points of the line segments served as basis in identification of the start and end of significant ECG time intervals. Along with R peaks coordinates, these end points were used in the calculation of the location of the other pertinent peaks.

Next was the correction of skewness through image rotation aided in producing an aligned image for proper retrieval of data points. ECG normalized amplitudes and time data points were retrieved at the given sampled time interval with an offset horizontal zero axis. This procedure was followed by the identification of the minimum and maximum values of amplitudes along with its time information on the left, and the right of R peaks and the horizontal line endpoints These maximum and minimum values identified the P, Q, S, and T estimated positions.

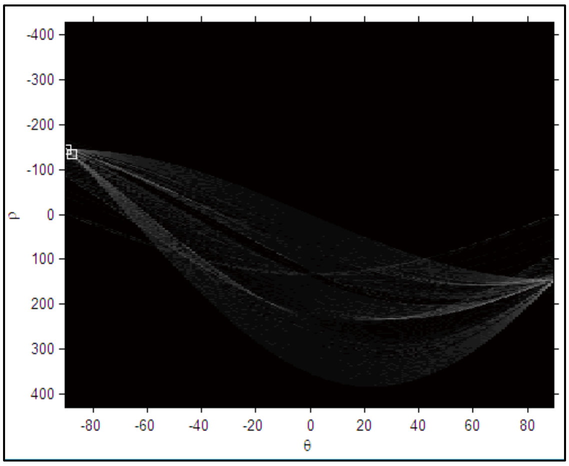


Figure 10: Plot of ρ (rho) vs. Θ (theta) of the evaluation of Hough transforms. Shown in white box the relevant horizontal lines whose theta equals -180 degrees.

Finally the system, through the Graphical User interface, determined whether the extracted features are within the normal limits. The basis for the classification of normal values is determined from the study entitled "Normal Values of the Electrocardiogram for Ages 16-90 years" conducted by Rijnbeek, P et.al [16].

D. *Performance of the system*

Finally, the root-mean-square error (RMSE) and Percent error were used to calculate the accuracy of the system. This formula, described in equation (3) & (4), is commonly used to compare observed data with theoretical or expected data. The outputs of the extracted ECG readings were compared to actual ECG reading values. Accuracy were calculated using percent error in equation (5).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left[x_{exp}(i) - x_{obs}(i)\right]^2}{n}} \quad (3)$$

$$Percent\ error = abs\,\frac{\left[x_{exp}(i) - x_{obs}(i)\right]}{x_{exp}(i)} x100\% \quad (4)$$

$$Accuracy = 100 - Percent\ error \quad (5)$$

where: x_{exp} = expected value,
x_{obs} = observed data and
n =the no. of samples.

V. RESULTS AND DISCUSSION

The image processing methods covered in this research processed the electrocardiogram strips printouts. Time boundaries with colored vertical line markings for P, Q, R, S, and T estimated positions were successfully marked, as seen in the Figure 11. From the time boundaries shown, PR interval, PR segment, ST segment interval, QT interval, ST interval as well as pertinent amplitudes of P, Q, R, S, T waves were noted. In a standard ECG, the width of a single small square represents 0.04 second, and the width of the bigger square consisting of five (5) small squares represents 0.2 second. The height of a single small square equals to 0.1 millivolt and thus the height of the bigger square indicates 0.5 millivolt. Based on the resolution of scanning used in this research, 59 pixels correspond to five (5) small squares. These were considered for the ECG feature extractions

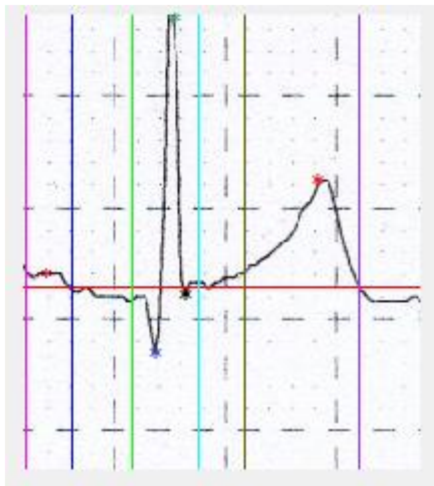


Figure 11: Example of one output with colored vertical time markings & dotted peak markings where ECG feature will be extracted

Graphical user interface (GUI) as shown in Figure 12 is created using MATLAB to easily view the extracted ECG information. An original ECG image is also incorporated with the GUI for reviewing the results of the ECG data. The menu on the middle part of the GUI includes a create profile button for indicating patient basic personal information such as name, age and gender. The delete profile button erases all records of a selected patient. A save feature is also included to store multiple ECG images of a particular patient along with age and gender information. At the top of the create profile button is the display for the original ECG image. The bottom section of this figure shows the ECG signal extracted features with standard units commonly seen in ECG readings. An indication of a red font is used to alert the user for readings which are outside the range of normal values based on age and gender.

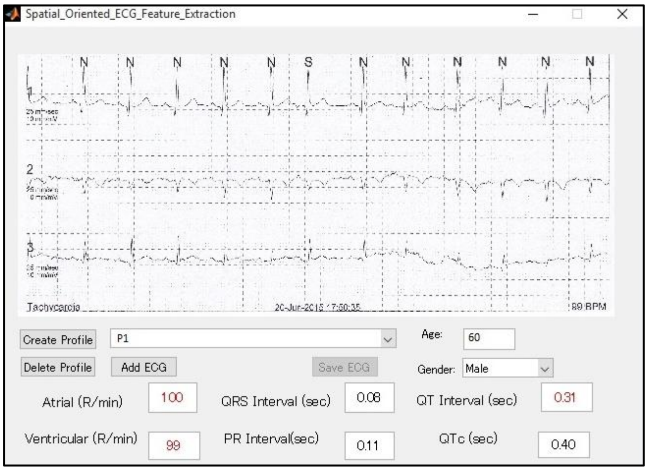


Figure 12. Example of GUI output

An example of a Graphical User Interface (GUI) display is shown in Figure 5 above. Readings in black color fonts such as QRS interval, PR interval and QTc are said to be within normal limits. However, according to the study of Rijnbeek, P et.al [16], the normal limits of Atrial and Ventricular heart rate is 48 to 95 bpm. Similarly, the normal values for QT interval based on the given age and gender is from 0.346 to 0.454. The ranges were based on 2nd percentile and 98th percentile of the results of the study. Thus, the heart rates as well as the QT interval were displayed in the GUI in red fonts.

Fifteen ten-second ECG charts were processed and compared with original ECG data for performance evaluation. Root-mean-square error (RMSE) of each feature extracted were computed and summarized on Table 1. The RMSE represents the sample standard deviation of the differences between the expected values and the observed values

Table 1
RMSE of ECG Feature extraction results

ECG Features	RMSE
Atrial	9.402
Ventricular	8.426
PR interval	0.032
QRS interval	0.029
QT Interval	0.025
QTc	0.022

Comparison with RMSE with different units can be made using the non-dimensional forms of the RMSE, normalized RMSE given by the Equation (4).

$$NRMSE = \frac{RMSE}{X_{obs}} \tag{4}$$

The details regarding normalized RMSE for each extracted feature are shown in Table 2.

Based on the normalized RMSE as shown in Table 2, QTc feature extraction performed best while Atrial, Ventricular, and QT interval worked equally well. QRS interval and PR interval achieved relatively poorer performance among the feature extractions.

The mean of corresponding accuracy calculated from percent errors for each of all fifteen ECG strips are also computed and can be seen in Table 3.

Table 2
Normalized RMSE of the extracted ECG features

ECG Features	NRMSE
Atrial	0.099
Ventricular	0.086
PR interval	0.203
QRS interval	0.350
QT Interval	0.074
QTc	0.053

Table 3
Average Accuracy based on percent errors

ECG Features	Average Accuracy
Atrial (rate/min)	92.807
Ventricular (rate/min)	93.3988
PR interval (sec)	87.196
QRS interval (sec)	95.000
QT Interval (sec)	95.034
QTc(sec)	95.424

The methodology achieved an accuracy of as high as 95.424 %, while the PR interval feature extraction achieved a relatively low accuracy of 87.196 %. The proposed methods here are highly dependent on ECG images obtained. Noisy ECG readings in printouts as well limitations brought by wandering baseline and Fuzzy baseline affected the effectiveness of the feature extractions using the proposed methods.

VI. Conclusion

This paper proposed an alternative yet effective way to process fifteen (15) ECG printouts to extract amplitudes and P, Q, R, S, T positions and time intervals. ECG features were extracted using spatial oriented image processing techniques. Overall, different values such as heart rate Atrial (rate/min) and Ventricular (rate/min), QRS interval (sec), QT interval (sec), QTc (sec), and PR interval (sec) were successfully extracted with indication of accepted normal values given the patient's gender and age. However, to improve the performance of the system, particularly in obtaining PR interval, high resolution images are required. ECG readings in printouts should be free of limitations brought by wandering baseline and Fuzzy baseline. An increase on the sample size may address variability and would further justify the accuracies obtained. Also as an extension, a comparative study with other similar research may be performed.

This research can be an aid tool to assist the physicians on reading ECG printouts hence, medical diagnosis. The GUI developed is also capable of storing multiple ECG images for records keeping for patients. The research can further be developed for data acquisition for a national health survey. In the Philippines, there are limited existing programs to survey non-communicable diseases, particularly cardiovascular diseases, and there have been limited attempts for profiling heart failure. [17], [18]. The data that can be collected through ECG can be the basis for multicenter clinical trials on cardiovascular diseases in general and heart failure in particular. Decision support system can further be added using arrhythmia classification algorithms [19].

ACKNOWLEDGMENT

Thanks to Erwin Isidro, M.D and Kelvin Choi Tsang, M.D who helped in providing the experimental data and giving technical suggestions. This work was supported by FEU Institute of Technology and De La Sale University where the authors are connected with.

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