Building an Automatic Arrhythmia Detection Software Based on Matlab

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Abstract

Electrocardiogram (ECG) is an electrical signal containing information about the condition and functioning of the heart. Nowadays, many types of arrhythmias can be efficiently diagnosed based on this signals. In this study, we developed a software based on Matlab GUI to analyze ECG data recorded from the ECG 9620 Nihon Kohden device. The software read data, calculated Heart Rate, detected and analyzed PR, RR, ST intervals and width of QRS. Algorithms were developed to identify arrhythmia. Moreover, the software is very friendly to users and allowed medical doctors and staff to work and analyze those data conveniently. We tested the software with over 200 ECG data obtained from a simulator and patients monitored by experts and medical doctors. The software could recognize 12 types of common arrhythmia types with good precision. These results indicated that our software is useful to support medical staff to detect arrhythmias.

Keywords

Arrhythmia detection software • Arrhythmia • Matlab

1 Introduction

An Electrocardiogram (ECG) signal can be used to measure the rate and abnormality (if present) of heartbeats, to detect disease or damage of the heart, and also to observe the effect of drugs or devices which alter the heart activity. Generally, the amplitude range of a normal ECG signal is from 5 to 10 mV and the frequency range is between 0.05–100 Hz [1].

The Q, R and S wave of ECG signal are considered as a whole complex, because they occur in rapid succession and do not all appear and reflect a single event. The QRS complex-wave signal has the normal duration from 0.06 to 0.1 s. A Q wave is any downward deflection after the P-wave. An R-wave is an upward deflection and the S wave is any downward deflection after the R-wave. The amplitude, duration, and interval between each of these waves help us distinguish between normal and abnormal waveforms. Certain diseases and their identification from an ECG signal are dependent on the characteristics of these waves.

Therefore, the variability of ECG signal should be observed over several hours for reliable diagnostics. As a consequence, the volume of amount the ECG data is enormously, this makes the study tedious and time consuming. Thus, automatic classification of heart arrhythmia is critical in clinical cardiology, especially ECG arrhythmia can be electrically defined as any of a group of conditions causing an irregular heart beat. It can take place in a healthy heart and cause a minimal consequence, but it may also indicate a serious problem that leads to stroke or sudden cardiac death. ECG signal is a non-stationary signal, so the arrhythmia may randomly occur in the time-scale. It means that the arrhythmia symptoms may not show up all the time but appear at certain irregular intervals discovered in the intensive care unit during the day for the patient's treatment.

MATLAB is widely accepted as one of the most powerful data processing platform. Its connection with more advanced programming language (such as C, Java, VB) and the

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availability of a variety of toolbox makes it popular in the scientific and research community [2]. In this study, we developed Matlab functions which were used to create a specific software.

We built the software that can reconstruct the ECG signal from the image of ECG data and reduce noise of signal before analysis. The software can also detect, calculate and analyze the PR, RR, ST intervals and QRS width of ECG signal. Based on these parameters, the software will detect and classify 12 types of heart diseases. Moreover, the software has some useful utilities help to analyze data on the interface of the software.

2 Materials and Methodology

(A) *Data acquisition*: ECG samples were taken not only from ECG Simulator but also from patients treated hospitals by Nihon Kohden 9620L device. Medicine doctors who work in the hospitals measured ECG on eight patients. Then, we collected the ECG data from ECG device under monitor of the medicine doctors. We also committed to the hospital that these ECG data are only used for research purposes. All ECG samples were images of ECG data. Matlab software is used for computer programming.

(B) *Algorithm Description:* Fig. 1 illustrates the block diagram of our algorithm. Our algorithm mainly includes 3 steps: Pre-processing, Feature Extraction and Classification.

(i) *Pre-processing:*

The input image is color image in *(.jpg)* format which is 24 bits image and has three channels as R, G and B. We calculated the ratio of each channel that helps us to convert color image to grayscale image. So, we can eliminate most of redundant color pixel of image.

O(x, y) is the output value of the pixel after changing. After that, appropriate threshold *(C)* is used to access pixel of ECG signals exactly and remove remain redundant pixels. If output value *O(x, y)* is smaller than threshold value *(C)*, value of pixel *O(x, y)* will be set as "*0*". In the contrary, value of pixel is "*255*" if output value is larger than threshold value.

ECG image can only illustrate 5-seconds of ECG signal. Figure 2 shows the input image of normal ECG which obtained from ECG simulator by ECG device.

After separating ECG data from image, algorithm is used to scan image of 12-leads ECG again and separate each lead *(A)* of ECG data by:

$$\boldsymbol{A} = [\boldsymbol{x};\boldsymbol{y}] = (\boldsymbol{x_t},\boldsymbol{y_t}) \le \boldsymbol{C}$$
$$\boldsymbol{with} \begin{cases} \boldsymbol{x_t} \in [\boldsymbol{x_{min}} : \boldsymbol{x_{max}}] \\ \boldsymbol{y_t} \in [\boldsymbol{y_{min}} : \boldsymbol{y_{max}}] \end{cases}$$

When 12-leads ECG are separated completely, linear interpolation method is used to reconstruct ECG data from image. The algorithm can be written as:

$$y = \left\{ \frac{x_i - x_{i+1}}{y_i - y_{i+1}} (x - x_i) + y_i | x \in [x_i; x_{i+1}] \right\}$$

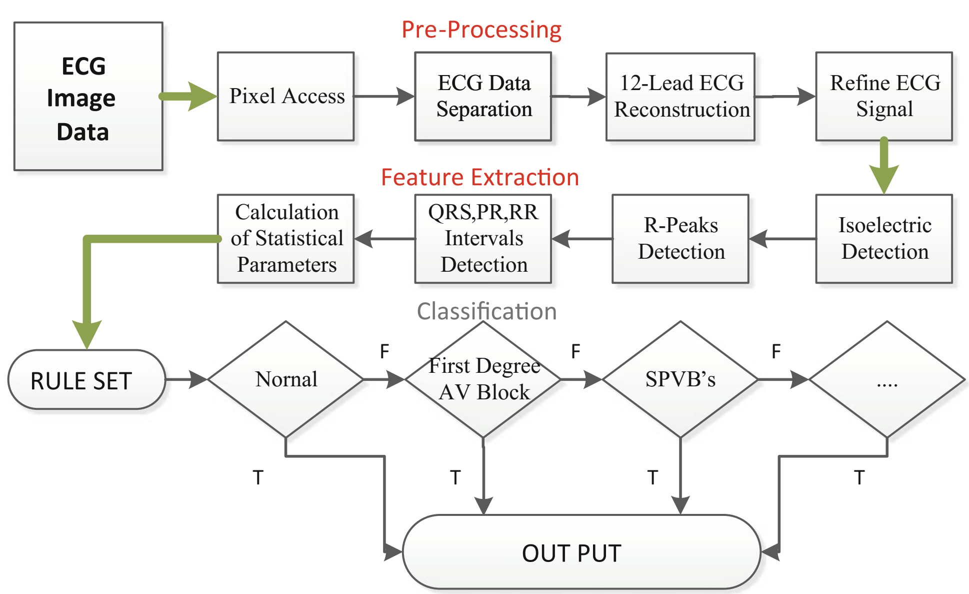

Fig. 1 Block diagram of algorithms

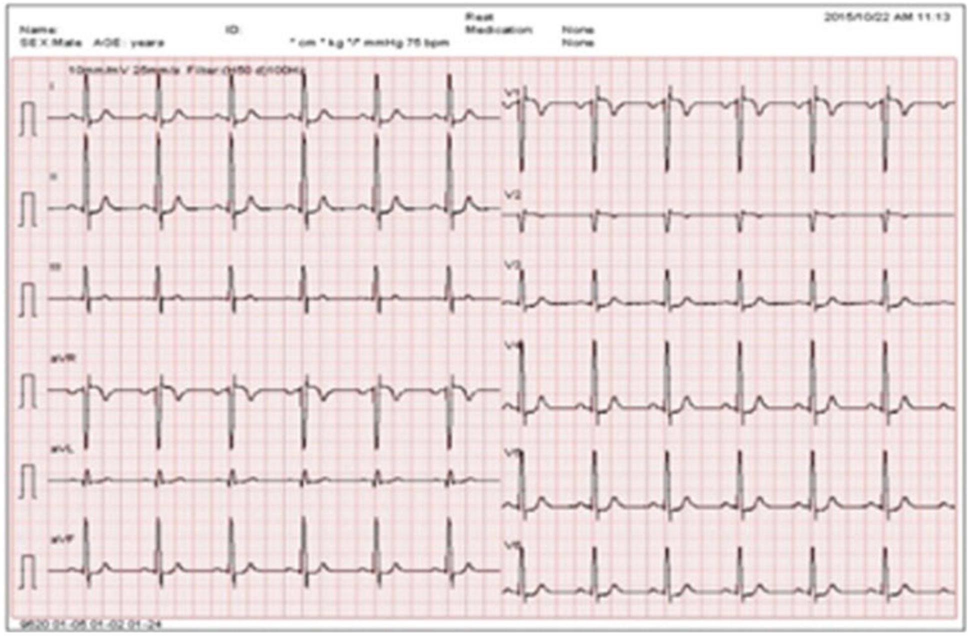

Fig. 2 Input ECG signal

These input ECG data are compressed into digital image. Therefore, the 12-lead ECG signals are overlapped when pixels are linked to each other. In addition, many redundant pixels appear in ECG signal because of noises. These problems may make R-R, P-R intervals and QRS complex detection erroneous. Because of that reason, algorithms are built to take average values of overlapped pixels that can reduce redundant pixels and overlap of ECG signal can be eliminated. X_i and Y_i are the locations of these pixels after processing by:

$$\boldsymbol{X} = [\boldsymbol{x_{min}} : \boldsymbol{x_{max}}] \rightarrow \boldsymbol{X} = [\boldsymbol{x}_1 \boldsymbol{x}_2 \ldots \boldsymbol{x_n}]$$

$$\boldsymbol{Y_i} = \frac{\sum_{x_t = X_i} (\boldsymbol{y_t})}{\boldsymbol{n}}$$

$\boldsymbol{n}$: number of elements (x_t) which satisfies the above condition.

However, the above algorithms will make amplitude of signal shorter than input signal. Therefore, we have to find the amplitude of each lead correctly.x and y represent two strings which are save as coordinates of signal after taking average value of pixels.

$$\boldsymbol{Z_k} = \{\boldsymbol{y_k} | \boldsymbol{x_k} = \boldsymbol{const}\}$$

$\boldsymbol{Y_t}$ represents the correct amplitude value of signal:

$$\begin{aligned} &\boldsymbol{y_k} \in \boldsymbol{Z} | \boldsymbol{y_k} = \boldsymbol{max}(\boldsymbol{y}) \\ &\boldsymbol{Y_t} = \boldsymbol{y_{max}} \\ &\boldsymbol{y_k} \in \boldsymbol{Z} | \boldsymbol{y_k} = \boldsymbol{min}(\boldsymbol{y}) \\ &\boldsymbol{Y_t} = \boldsymbol{y_{min}} \end{aligned}$$

As a result, ECG data are redrawn very clear and like the input data before analyzing.

(ii) *Feature Extraction*: Isoelectric can help us built algorithms to detect intervals of ECG signal and process signal.n_i is sequence of element (Y_i) appearances in the string (y). Isoelectric of each lead of signal can be presented by:

$$\begin{aligned} &\boldsymbol{y} = \boldsymbol{Y_i} \leftrightarrow \boldsymbol{n_i} = \mathbf{max}(\boldsymbol{n}) \\ &\Rightarrow \boldsymbol{y} = \{\boldsymbol{Y_i} | \boldsymbol{n_i} = \boldsymbol{max}(\boldsymbol{n})\} \end{aligned}$$

It is difficult to detect the P wave and QRS complex wave because ECG signal varies in time due to psychological conditions and the presence of noise. The first important issue is to find the maximum peaks in signals which are R-peak. Coordinate of R-peak is Y_i which is the max value in $[\mathrm{x_a}; \mathrm{x_b}]$. R-peak $(X_i; Y_i)$ is found out by:

$$\begin{cases} \boldsymbol{Y_i} = \underset{[x_a; x_b].}{\boldsymbol{max}} (\boldsymbol{Y_{max}} - \boldsymbol{d_Y}) \\ \quad \boldsymbol{X_i} \in [\boldsymbol{x_a}; \boldsymbol{x_b}] \end{cases}$$

PR interval is detected and calculated by the P wave detection. We analyze each R-R intervals of ECG signal based on isoelectric (**C**).

$$\boldsymbol{S} = \boldsymbol{x_i} | \boldsymbol{x_{i+1}} > \boldsymbol{C}\,; \boldsymbol{T} = \boldsymbol{x_i} | \boldsymbol{x_{i-1}} = \boldsymbol{C}$$

$$\boldsymbol{with}\, \boldsymbol{y} > 0 \,\&\, \forall \boldsymbol{x} \in [\boldsymbol{S}, \boldsymbol{T}] \boldsymbol{y} > \boldsymbol{C} \qquad \boldsymbol{T} = \boldsymbol{x_i} | \boldsymbol{x_{i-1}} = \boldsymbol{C}$$

$$\boldsymbol{PR} = [\boldsymbol{S}, \boldsymbol{T}]$$

Similarly, T wave can be detected by the above algorithm. Other algorithms are used for analyzing P-R, R-T intervals that help to calculate QRS width. *Q(x,y)* and *S(x,y)* are coordinates of Q and S on coordinate axes.

$$\begin{aligned} \boldsymbol{R} &= [\boldsymbol{R}_1, \boldsymbol{R}_2 \ldots \boldsymbol{R}_n]; \boldsymbol{X} = [\boldsymbol{X}_i | \boldsymbol{Y}_i = \boldsymbol{C}] \\ \boldsymbol{Q} &= \boldsymbol{X}_j | \boldsymbol{min}(\boldsymbol{R}_i - \boldsymbol{X}_j); \boldsymbol{j} < \boldsymbol{i} \\ \boldsymbol{S} &= \boldsymbol{X}_j | \boldsymbol{min}(\boldsymbol{R}_i - \boldsymbol{X}_j); \boldsymbol{i} < \boldsymbol{j} \\ \boldsymbol{QRS} &= \{\boldsymbol{S}_i - \boldsymbol{Q}_i, \boldsymbol{i} \in [1, \boldsymbol{n}]\} \end{aligned}$$

Based on these detected R-peaks we calculate the Heart Rate which is an essential information of ECG signal. Moreover, the software has some utilities for users to work convenient such as horizontal zoom, vertical zoom, save and load data.

(iii) *Classification:* RR, PR intervals and QRS duration play important roles in Arrhythmias Classification. Each type of arrhythmia has a specific feature. Therefore, decision rules were formed based on extracted features (RR, PR intervals and QRS duration). Recently several research algorithms have been developed for arrhythmia detection in ECG signals some of them are using various different decision rules. Mannurmath [3] built algorithms with normal QRS duration from 0.08 to 0.12 s and normal PR interval from 0.12 to 0.20 s. As a result, they found that the efficiency of detection is nearly around 98% as the data are compared with MIT-BIH database. In an others study, Gold [4] built his algorithms for detecting Arrhythmias based on the width of QRS of over 120 ms. PR interval is equal or greater than 210 ms and width of QRS complexes exceeding 126 ms that are these abnormal interval to detect some types of Arrhythmia. This decision rules are built in Willems and Pipberger [5] algorithms.

In our study, some algorithms were built based on the normal widths of QRS wave and PR interval. The former was from 0.06 to 0.11 s and the latter was from 0.12 to 0.20 s. Firstly, our software will identified RR, PR intervals and width of QRS waves. Then, the times of these intervals were analyzed and abnormal intervals detected. Values of these intervals were tested with 12 decision rules. If it was true, the type of arrhythmia was will be shown in the Gui-Matlab. In contrary, if it was false in all 12 cases, the result will be shown as Normal. Some of these classifying rules are:

(a) *Supraventricular premature beats (SVPB's)*

The QRS Complex, PR interval that are used for SVPB's detection. First condition is checked whether it is an abnormal QRS duration and abnormal PR interval. If this condition is also false then RR intervals is tested for single premature heartbeat, if yes then it is checked for SVPB's. Test condition for Single Premature Heartbeat with 0.2 s = 15 pixel:

$$15 < \frac{\sum_{i=1}^{n} (\boldsymbol{R}_i - \boldsymbol{P}_i)}{\boldsymbol{n}} < 37$$

(b) *First Degree AV block*

The QRS Complex and P-R intervals within that are used for *First Degree AV block* detection. If QRS durations are normal, PR intervals tested for *First Degree AV block*:

$$\boldsymbol{P} = \frac{\sum_{i=1}^{n-1} (\boldsymbol{R}_{i+1} - \boldsymbol{R}_i)}{\boldsymbol{n} - 1}$$

P = 1 is true condition of *First Degree AV block* while *P = 0* is false condition.

In our study, *DII (S1), AVF (S2), V4 (S3), V5 (S4)* are the 4 leads of ECG signal that are used to analyze signal and diagnose types of arrhythmia. The general classification algorithm can be written as:

$$\boldsymbol{S} = \frac{\boldsymbol{S}1 + \boldsymbol{S}2 + \boldsymbol{S}3 + \boldsymbol{S}4}{4} + 0.1$$

The software can only classify totally ten Arrhythmias because those input data are limited. We had to spend a lot of time to obtain data on arrhythmias patients who were treated in hospitals. Due to strict regulations of the hospitals, we faced many difficulties in collecting data. Thus, we could only measure on 8 patients with arrhythmias such as *Atrial Fibrillation, ST-Elevation* and Supraventricular Premature Beats. Furthermore, the simulator could only provide 12 types of arrhythmia data due to error of image file output. Fortunately, Arrhythmias data which were obtained from the simulator had no limit, so we could research on many different periods of samples that were very useful for our research.

Decision Rules created by our own algorithm could be used to detect all 12 Arrhythmias such as: *Tachycardia, Bradycardia, First degree AV block, Second degree AV block, Atrial Fibrillation, Atrial Flutter, Sinus Arrhythmia, Atrial Pause, Supraventricular Premature Beats, ST-Elevation, ST-Depression and Ventricular Tachycardia.*

3 Results and Discussion

Matlab-based GUI-driven tool was built for effective detection and using ECG signals to classify Arrhythmias. Totally 220 samples were tested, Table 1 shows the results

Table 1 Arrhythmia classification using our algorithm for some ECG signals

Process	Types												
	First degree AV block	Second degree AV block	Atrial fib.	Atrial flutter	Sinus arrhy.	Atrial Pause	SVPB's	ST-elev.	ST-depr.	V. tach.	Tachy.	Brady.	Normal
Patient data			6				6	6					40
Diagnose			4				6	6					37
Simulator data	20	20	20	20	20	20	20	20	20	20	20	20	20
Diagnose	19	17	20	20	20	20	20	20	20	20	20	20	20

of our proposed method for some ECG samples. Algorithm works fine for noise contaminated signals also.

Diagnosis of arrhythmia data was correct with *98%* reliability on simulator's data while Normal rhythm detection accuracy was *100%*. However, the diagnosis of cardiac arrhythmias was only *89%* accurate on patients and detection of normal rhythm had only *92.5%* reliability. Arrhythmia detection accuracy was dropped due to noise which had not been completely eliminated. As a result, the software will identifies wrong PQRST durations which may affect to analyze ECG signal for detecting Arrhythmia.

- *GUI building*: GUI for this software is divided into number of subgroups according to their functionality. Our software module detects not only arrhythmias but is also helpful in analyzing ECG signal.
- *Signal information panel:* This panel displays R-Peaks and calculates heart rate of signal.
- *Toolbar:* Importing ECG image data by "open" push tool, software can also save data in the (.MAT) format and reload (.MAT) data by "open" menu tool. Moreover, toolbar has some utilities such as horizontal zoom, vertical zoom, zoom in, zoom out, data cursor, pan which support users in data analysis.
- *Diagnose Panel:* if the patient is suffering with disease or not, if yes then what type of arrhythmia he's suffering with, can be found by "Process" push button then arrhythmia is displayed in box.

Figure 3 shows input sample taken is "0736" data file from patient. Proposed algorithm successful detected arrhythmia as "ST-Elevation" as shown in text box with blue coor.

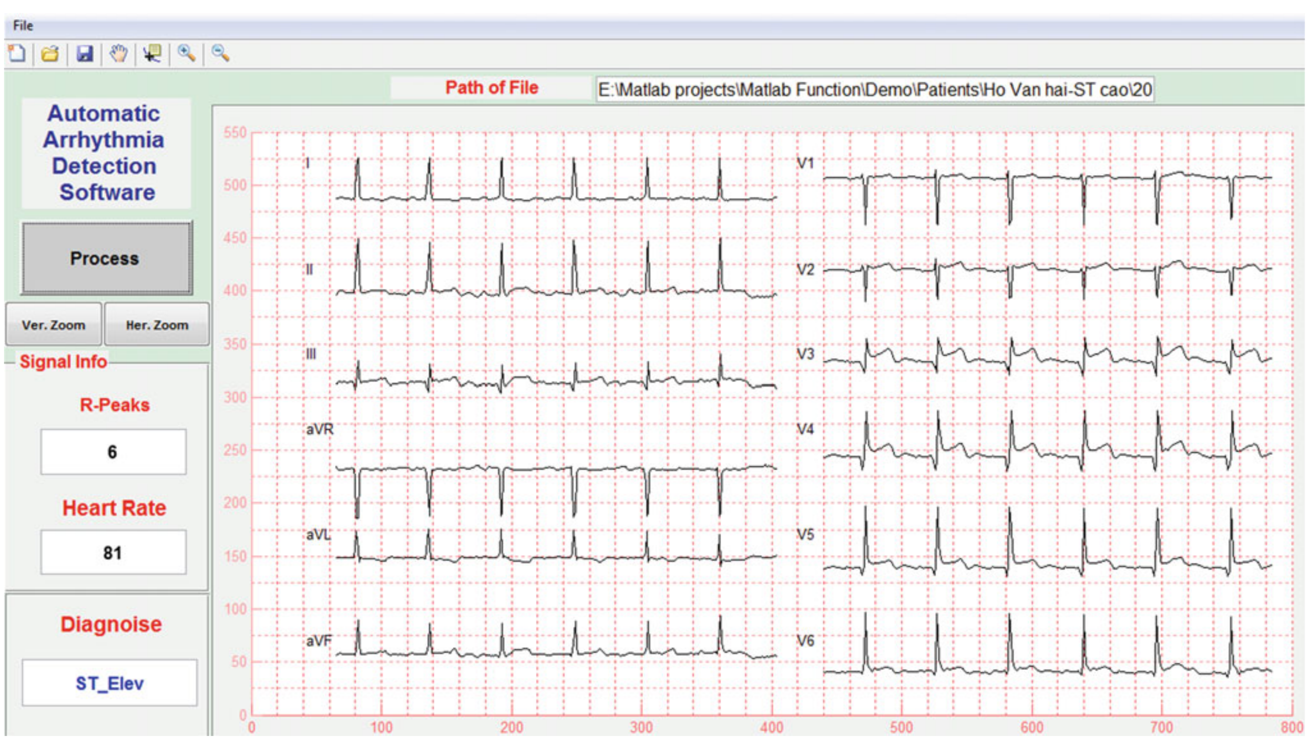

Fig. 3 Shows GUI after execusion

4 Conclusion and Future Work

In this investigation we have developed and tested effective and flexible software tool using Matlab for ECG arrhythmia detection. Our software tool can be extended to detect more types of arrhythmia and by implementing de-noising filters we can increase accuracy for our algorithm. To the best of our knowledge there is no software tool based on Matlab GUI that can detect these many arrhythmias by analyzing ECG image data recorded from Nihon Kohden 9620L. Obtained results indicate that proposed algorithm can support various types of arrhythmia detection in clinical tests.

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