Electrocardiogram Data Capturing System and Computerized Digitization using Image Processing Techniques

Lai Khin Wee, Yeo Kee Jiar, Eko Supriyanto

***Abstract*—**Electrocardiogram (ECG) is one of the most widely used diagnostic tools for heart diseases nowadays. Nevertheless, the accurate ECG interpretation is essentially required in order to evaluate the valuable information inside the ECG signal. The conventional technique of visual analysis to inspect the ECG signals by doctors or physicians are not effective and time consuming. Therefore, an automatic system which involves digital signal integration and analysis is required. This paper presents the developed software for image capturing from ECG machine by using digital webcam camera and performing analysis on the captured ECG graph in display before sending through the internet network. The implementation of this project is using MATLAB mathematical software (version 7) as well as the signal and image processing toolbox. Test results show that this software able to extract information from ECG image or video based file and the system manage to determine heart rate of captured ECG accurately.

***Keywords*—** Electrocardiogram (ECG), peak detection, QRS detection, RR intervals, signal transmission, system.

I. Introduction

THE electrocardiogram (ECG) is a graphical representation of the electrical activity of the heart and is obtained by connecting specially designed electrodes to the surface of the body [1]. It has been in use as a diagnostic tool for over a century and is extremely helpful in identifying cardiac disorders non-invasively. The detection of cardiac diseases using ECG has benefited from the advent of the computer and algorithms for machine identification of these cardiac disorders.

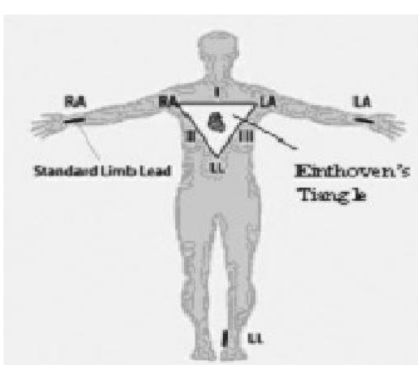

Fig. 1 The placement of the bipolar leads

In 1906 Einthoven [8] invented a new dimension by introducing the concept of vectors to represent the ECG voltages. He is also the first individual to standardize the electrode locations for collecting ECG signals as right arm (RA), left arm (LA) and left leg (LL), and these locations are known after him as the standard leads of Einthoven or limb leads, as shown in Figure 1. The limb leads consist of six unipolar chest leads, starting from lead V1 until V6 in an electrocardiogram, as shown in Figure 2 below.

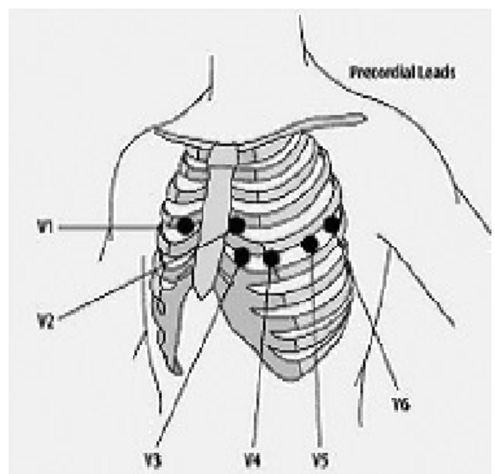

Fig. 2 The placement of the exploratory electrode for the unipolar chest leads (Right image) in an electrocardiogram

Most of the cardiac disease classification algorithms begin with the separation or delineation of the individual ECG signal components. The ECG signal comprises of the QRS complex, P and T waves as shown in Figure 3. Occasionally a U-wave may also be present which lies after the T-wave. The QRS complex is the most distinguishable component in the ECG because of its spiked nature and high amplitude as it indicates depolarization of the ventricles of the heart which have greater muscle mass and therefore process more electrical activity [3]. Detection of the QRS complex is one of vital importance in response to the subsequent processing of the ECG signal such as calculation of the RR interval, definition of search windows for detection of the P and T waves and etc. In terms of disease classification, the QRS complex is of pathological importance and its detection serves as an entry point for almost all automated ECG analysis algorithms [2].

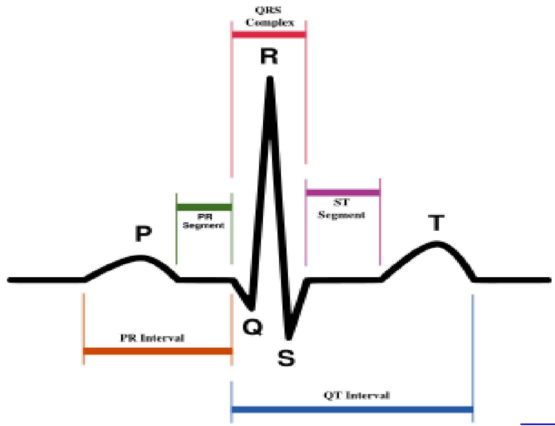

Fig. 3 Typical single cycle of ECG signal

Due to its importance and extensive contribution in healthcare, ECG amount in hospital has increased tremendously. Normally, ECG has to be printed on a thermal paper for further physical inspection by medical doctor. Therefore, a reasonable physical storage space in the hospital for this storage of records is essentially required. Also, the conventional visual analyses to inspect the ECG signals are absolutely not effective and time consuming, especially in hospitals that are highly patient load. Retrieving the ECG record from the hospital archive is another equally time consuming and laborious. For that reason, efforts have been made by numerous investigators worldwide to try to find an approach for accurate and fast ECG digital time series signal extraction. The benefit of converting these ECG records into a digital time series are not only reduces the physical storage spaces, it also enable for some automatic computerized algorithms for important information extraction in rapid and precise way.

Jalel Chebil et. al. [6] had proposed digitization method of ECG signal from scanned images based on binary conversion. However, the drawback of their method is the binary thresholds selection are not based on the nature of image, background grid of thermal paper cannot be eliminated absolutely and causing some information loss during the signal extraction. A. R. Gomes e Silva et. al. [7] suggested the extraction of signal can be performed by discarding the axis and performing a median filtering operation on the resultant image. Nevertheless, the removal of the axes leads to the further complexity in obtaining the ECG morphological details. Tsair Kao et. al. [9] also presents a morphological approach in order to remove the background grid from the scanned ECG thermal paper. Their algorithm depends heavily on the binary conversion of scanned image for the estimation of periodic distance vertical direction (PDVD). The removal filter integrates with XOP operator is used to perform of the first binary PDVD image and its shift version. Sucharita Mitra et. al. [14] proposed an automated ECG data extraction system from ECG strips by using some image processing techniques. A rule-based rough set decision system is generated eventually using these time-plane features for the development of an inference engine for disease classification. Their algorithms have implemented two sets of rules for this purpose, where the first set of rule is for common division connecting usual and unhealthy subjects, and the second set of rules is purposely applied for the classifications between different kinds of diseases.

In this paper, the detection of RR interval serves as the core of project in order to calculate the heart rate of patient. According to previous researches in literature, there are a number of algorithms have been developed to determine heart rate and kind of diseases based on detected electrocardiogram. For example, Prashanth Swamy et al. had proposed an improved method for digital time series signal generation from scanned ECG records [5]. Their proposed technique is another approach to compute the RR internal for heart rate calculation from the obtained time series to facilitate the evaluation of the methodology.

Some other existing algorithms employ a specific QRS template, which might also be considered as the best way to prevent the QRS detection performance from being degraded by the undesired noise sources, including baseline drifts, artifacts due to electrode motion or power-line interference, and the waves with similar morphology to QRS complexes, such as P or T waves [4]. However, since the template techniques involved the digital ECG signal as the input of developed algorithm, it is obvious that the outputs of older version ECG machines are not able to integrate with this expert system. In other words, the inputs of these intelligent systems are not compatible with those output from conventional ECG machine.

The unique of proposed project in this paper is serving ECG image as the input of developed algorithm by implementing a low cost digital webcam camera to capture the ECG signal in displayed at ECG machine screen. Some simple and reliable image processing techniques was also proposed before analysis of heart rate calculation. Measurement result will be shown in self-generated report and sending through the internet network. In section 2, we describe the background studies of previous research. Section 3 explained the materials and method and result are discussed in Section 4. We also draw some discussions and conclusions in Section 5 and Section 6 respectively.

II. Background

A previous research was investigated by a research group from Ragnar Granit Institute, Tampere University of Technology, Finland which using mobile phone to implement the ECG information transmission. They introduce an ECG measurement, analysis and transmission system through a mobile phone as a base station. The system is based on a small-sized mobile ECG recording device which sends measurement data wirelessly to the mobile phone. In the mobile phone, the received data is analyzed and in cases of any abnormalities are found among parts of the measurement data; it will be send to a server for the use of medical personnel simultaneously.

The prototype of the system was made with a portable ECG monitor and Nokia 6681 mobile phone. The results show that modern smart phones might capable for this kind of tasks. Thus, with very good networking and data processing capabilities, they might be a potential part of the future wireless health care systems. When requested, the application also displays the ECG signal and heart rate on the phone screen. The view the received ECG signals on the phone screen along with the measured heart rate are illustrated in Figure 5. In addition, an informative Short Message Service (SMS) - message is delivered to the mobile phone of a selected person if so chosen. The main tasks of the different parts of the system are shown in Figure 4. However, due to the limits of electronics support and processing unit within the mobile phone, the overall performance is hardly operated in an ideal condition. The display screen of mobile phone is smaller than any conventional ECG machine display and some important morphology of the ECG signal might not able to be observed. Delayed in data transmission might also disrupted the data analysis and measurement in consequences. To avoid these, the proposed project in this paper are implementing the images based techniques and digitization ECG signal through digital camera for input capturing, information extraction and analysis using MATLAB tools as well as data sending system based on internet network.

In addition to automated analysis, the proposed application offers a possibility for a patient to send an alarm if he feels anxiety, faintness or other distress. The result of sending an alarm is the same as exceeding the heart rate limits. That is, a predefined amount of measurement data around this event is sent through the internet network.

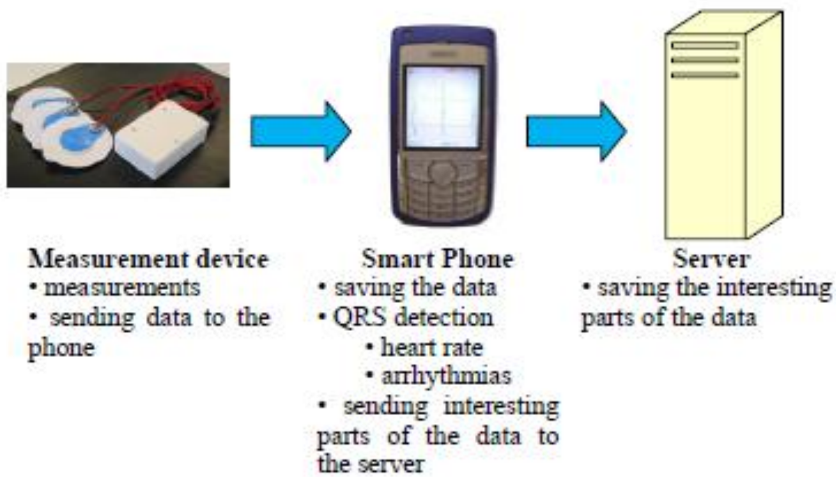

Fig. 4 Main tasks of the different parts of the system

Fig. 5 The phone screen when the signal drawing mode is activated

III. Materials and Method

The algorithm is start with ECG image capturing by using a real time operating digital webcam camera and saved in the computer. The format of captured image above can be JPG, TIFF, BMP and etc. Besides, the algorithms can also integrate with off time input signal either in video based file or prior saved image in the computer as well. Then the algorithms are follows by a series of image processing techniques that perform image conversion, image filtering, image enhancement, and image cropping. The processed ECG image will be analyzed for the detection of distance between R peak to peak, in order to calculate the heart rate. Lastly, a sending report will be self-generated which includes all the information regarding patient's data and heart rate measurement result. The flow chart displayed in Figure 6 shows the procedures of developed algorithm.

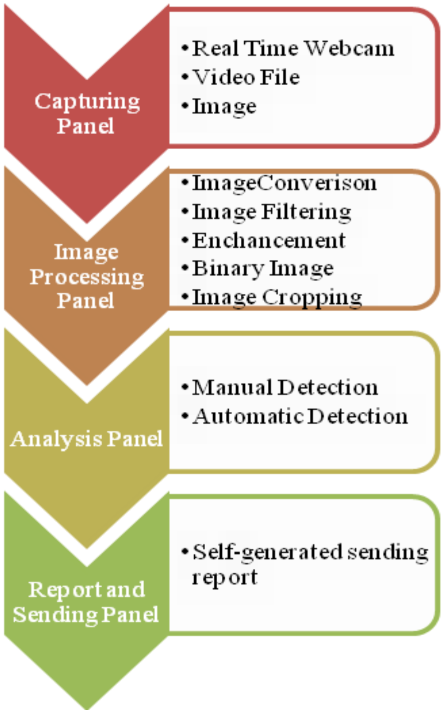

Fig. 6 Procedures of developed algorithm in different panels

A. Capturing Panel

Based on Figure 6, the developed capturing panel provides three distinct ways to feed image as the input for the following image processing panel. Firstly, the user can activate the real time operating webcam in order to get the snapshot of ECG signal from ECG machine. Meanwhile, the algorithm also allows the user to implement the off time input such as recorded ECG video based file or prior saved image in computer. After the selection of input methods, it is followed by some reliable image processing techniques for the elimination of undesired noise.

B. Image Processing Panel

The first step in this panel is to eliminate the hue and saturation information while retaining the luminance of the image. This can be done by converting the true color image RGB format to the grayscale intensity image format. This conversion is essentially required due to the subsequent image filtering that can only able to be performed on grayscale image. Image filtering will make the ECG signal line sharper than the noise behind the image background. Or in the other words, the implemented Laplacian image filtering making the pixel values of the ECG signals less than the noise in image background. As consequence of this, less information will be lose during the binary image conversion later. The following mathematical equations is the Laplacian filter for the image filtering, where the parameter alpha controls the shape of the Laplacian and it must be in the range of 0.0 to 1.0. The default value for alpha in MATLAB mathematical software is 0.2.

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \qquad (1)$$

$$\nabla^2 = \frac{4}{(\alpha+1)} \begin{bmatrix} \frac{\alpha}{4} & \frac{1-\alpha}{4} & \frac{\alpha}{4} \\ \frac{1-\alpha}{4} & \frac{\alpha}{4} & \frac{1-\alpha}{4} \\ \frac{\alpha}{4} & \frac{1-\alpha}{4} & \frac{\alpha}{4} \end{bmatrix} \qquad (2)$$

Image enhancement is an additional improvement for the image quality. The pixels values between the ECG signal and those undesired noise in the background will be compared and one threshold value will be chosen. If the interested line with the pixels values close to the threshold value, its pixels value will be subtracted about 20 to make it dim. Reversely, the undesired noise with the pixels values close to the threshold value, its pixels will be added about 20 to make it light. Therefore, the resulting image will contains distinct ECG signal in the image. The experimental results of image before and after the enhancement technique are shown in following figures.

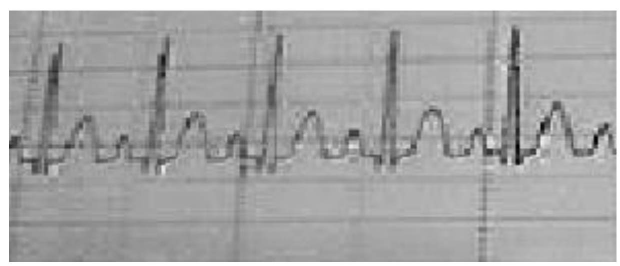

Fig.7 Example of image before Image Enhancement

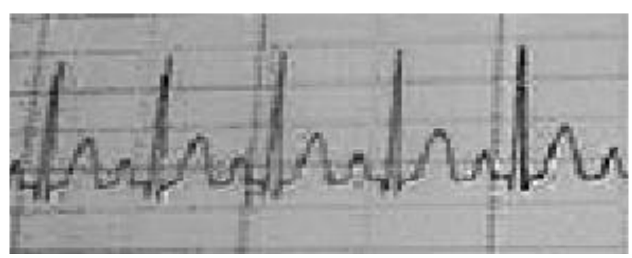

Fig. 8 Example of image after Image Enhancement

Furthermore, the resultant image will be converted as the binary image in which the output replaces all the pixels in input image with luminance greater than level with the value 1 (white) and replaces all other pixels with the value 0 (black). Last but not least, only the interested region of the image will be cropped and posses through analysis panel.

C. Analysis Panel

The function of this panel will be the core of the project to calculate the heart rate of patient simply based on digitized ECG image. The idea behind this panel is to make use the distance measurement between the R peak to peak selections in the ECG signal. Average of multiple distance measurement will be computed as the final heart rate of the patient.

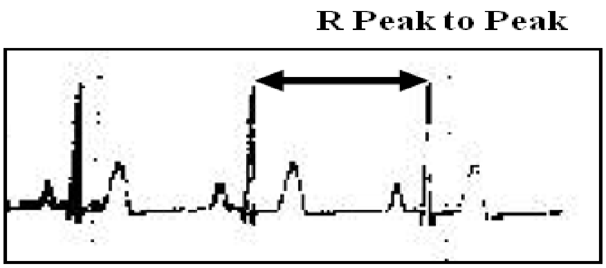

Fig. 9 Example of RR intervals

For manual calculation, the user will ask to provide the time division of ECG machine display. The software allows the user to select the R peak to peak and the distance between the selected two points will be calculated within the time division. The results of the calculation will be the heart rate of the patient. The Figure 9 shows the distance between R peak to peak selections in an image. However, the automatic panel is able to calculate the distance between R peak to peak automatically rather than asking user to select it manually. The algorithm will scan through the image starting from the left upper corner to the right lower corner of the image and all the black pixels will be stored in a new vector M. The variable of pixels *i* and *j* in vector M (*i*, *j*) is shown as equation 3 below:

$$M(i, j) = \sum_{i=0, j=0}^{i=N-2, j=N-2} \mathrm{Im}(i, j) \tag{3}$$

Where Im (*i*, *j*) = 0 initially

The variables of image will equal to zero when it was black in binary image and stored in new M vector. The RR interval can be calculated based on M vector above by setting a threshold value to validate the calculated distance.

D. Report and Sending Panel

The last stage of the project's activities is self-generating report and sending panel. After the image gone through the image processing panel and analysis panel, a report including all the patient's information data and heart rate will be generated and sending through the internet connection. In addition, one comment box was set in the report for the users to add on some important notes for their recipients.

IV. Result

The implementation of algorithm above will results a report including patient's data and accurate heart rate calculation. In this section, the results of algorithm for each image processing techniques were shown. First of all, the selected ECG image was initially loaded into the software through computerized algorithms. The converted raw ECG image in grayscale is shown in the Figure 10. It is obvious to observe that the ECG signals in the raw image are not clear and mixed with disrupted noises due to the low resolution of the camera. For that reason, image filtering playing a vital role here to extract the interested signal and eliminate the undesired noise simultaneously. Figure 11 below illustrated the results of image filtering.

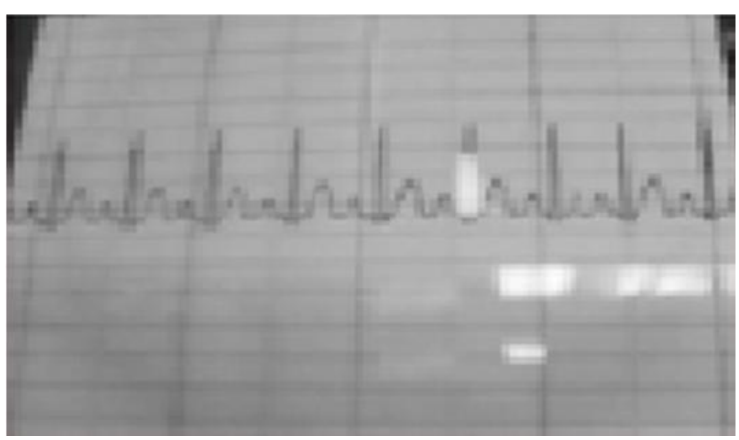

Fig. 10 Initial ECG image in grayscale

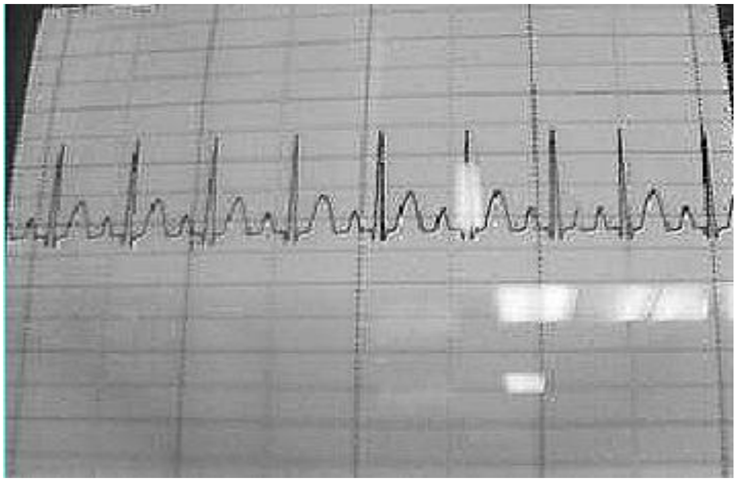

Fig. 11 Output after image filtering

Accurate digitization of ECG signal depends heavily on the quality of given image. To ensure the promising quality level of ECG signal in the relevant image, the developed algorithm will further enhances the pixels in ECG lines, as discussed in previous section 3.2. The appearance of the ECG signal within its background image was distinguished from the ECG signal, as shown in Figure 12.

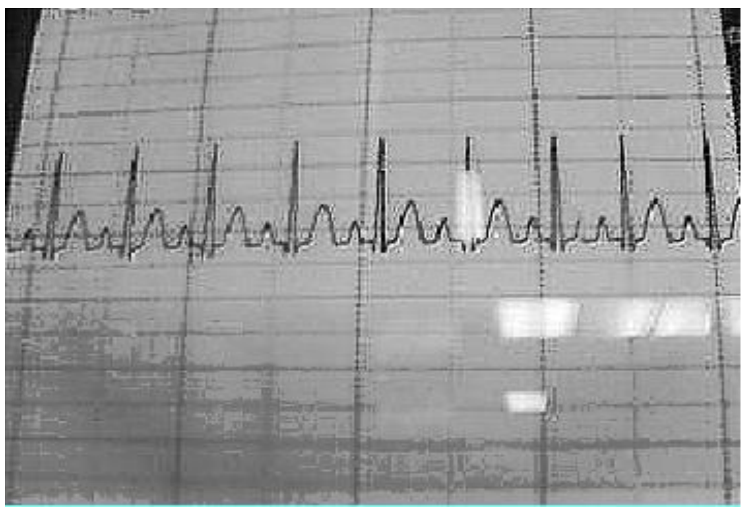

Fig. 12 Output after image enhancement

Eventually, the resultant image will be converted as binary image where the threshold value for the binary conversion is 0.5, the default value used in MATLAB command. Figure 13 shows the resultant binary image of the developed software.

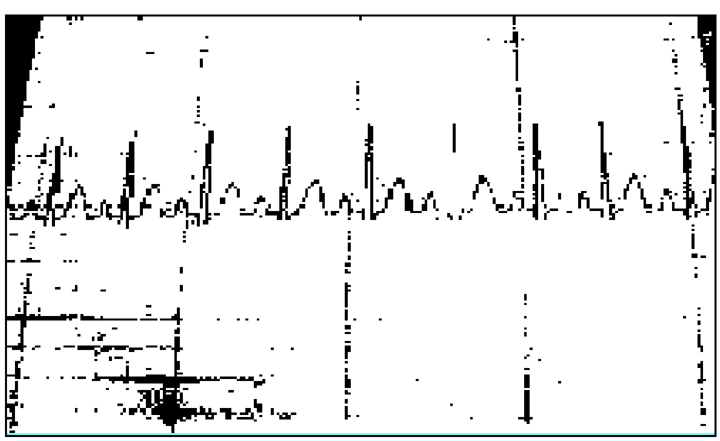

Fig. 13 Output after binary image conversion

As far as we concerns is the detection of positive RR intervals, therefore it is necessary to crop the resultant image above and avoid the noise from the image. The image after cropping function is shown as following figure.

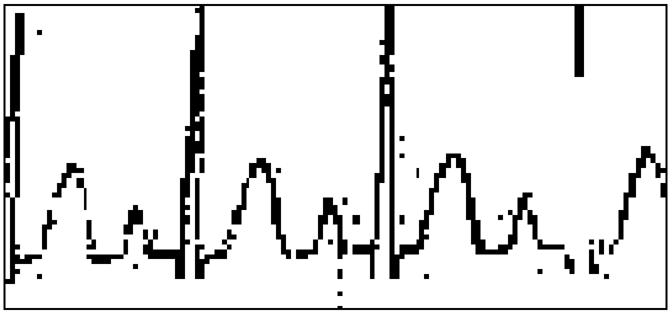

Fig. 14 Output after image cropping

Based on the simulation results, the algorithm can detect the RR intervals automatically by creating a new vector which contains the variable of all black pixels in the ECG lines. However, one problem can occurs which lead to fault heart rate calculation if undesired noises are located at the position higher than the R peak in the image. Therefore, it is recommended the user to crop the resultant image in which a way to avoid the noise upper than R peak in ECG signal.

V. Discussion

It is not effective and efficient to interpret the ECG signal's information by using the conventional technique of visual analysis to inspect the ECG signals. This method is essentially more complicated and time consuming. Also, only the experts who are wide experience in this medical field are able to interpret the ECG displays by using bare eye. Since the human being cannot avoid from technical error, sometimes wrong information or diagnosis would be occur especially in hospital with high patient's load. The needs of making use the digital computer technologies is arise and many artificial intelligent systems have been developed to make this job easier and effectively. This includes the focus of digitization of ECG signal extraction, pattern recognition, automatic ECG evaluation and abnormality heart diseases detection. Pattern recognition approaches are widely used for the detection and analysis of these waves. For example, direct signal pattern analysis, non-linear signal transformations, principal component analysis, and neural networks (NN) based techniques are used for ECG pattern recognition and classification [10-13, 22-23]. Also, recently some investigators worldwide have applied different forms of wavelet transform to decompose ECG signal for detection of P wave by neural network [15-21, 24]. This system always involves the digital software analysis method to help the doctors or physicians to diagnose heart disease based on recorded ECG signal from ECG machine. The future researches should focus on how to implement the concept of telemedicine for this digital intelligent software. So that physiological monitoring process of the patient can be conducted at anywhere and anytime.

VI. Conclusion

As a conclusion here, automation data capturing and sending system based on digitized ECG image have been developed. Such automation system especially for medical purpose is very important and required in telemedicine purposes. This is because it enables the patient monitoring process with the medical devices without any wire connections. In this project, the output of the developed program will be a self-generated report which including patients' information and heart rate. It will then be send through the internet connection to the user's recipients.

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