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ECG Based Expert System for Helping Doctors to Diagnosis Heart Abnormalities

Jannatul Maowa[1,*], Syed Muhammad Asifur Rahman[2], and Mohammad OsiurRahman[1]

[1] *Department of Computer Science and Engineering, Faculty of Engineering, University of Chittagong, Bangladesh*

[2] *Department of Ophthalmology , Chittagong Eye Infirmary and Training Complex, Bangladesh*

**Corresponding author*: smaowa@gmail.com

Keywords

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Cardiac cycle
Feature extraction
P-QRS-T segment

Abstract

Electrocardiogram (ECG) is a significant investigative tool for the identification of any abnormalities in heart function. In actual fact, the correct ECG reading is mandatory for evaluating the valuable data from the signal of ECG. The pictorial analysis of conventional technique to examine the signal of ECG by physicians or doctors are non-effective as well as time consuming. This process also needs extensive manual effort and huge storage space. For classification of ECG signals, a computer-supported application model is discussed in this research for detection of cardiac abnormalities. The model is built on a number of prevailing procedures in literature which were adjusted to outfit this proposed application. The developed model comprises pre-processing of ECG signal, mining of various morphological features by wavelet transform as well as classifying it with support vector machine. In this article, for developing user friendly application, a user interface (UI) is designed in MATLAB based environment which then builds it serve completely as a cost-effective expert application to evaluate the signals of ECG for detection of heart irregularities. The performance of the developed expert application was inspected using 120 samples of ECG image. The application is fast, easy to use as well as provides the outcome of diagnosis as 'Normal' or 'Abnormal'. The experimental results - accuracy of 95%, sensitivity of 95.23%, specificity of 94.7%, positive predictivity of 95.23% and detection error rate of 9.5% displays that the developed expert application may be worked for the identification of heart diseases.

1. INTRODUCTION

The finding of the signal of ECG has been widely used for identification of numerous cardiac ailments. Actually, ECG is a time record of the direction as well as magnitude of the electrical act that is produced by depolarization of atria and ventricles. In ECG signal, one cycle indicates the P-QRS-T complex. Figure 1 shows an instance of the signal of ECG. The sign of ECG is generated by the intervals as well as amplitudes cleared by its features, e.g., characteristic wave peaks as well as time durations.

The progress of methods involved in the feature extraction of ECG is that the foremost vital, mainly for the inspection of long record [1]–[3]. The system of ECG feature-extraction delivers rudimentary features (amplitudes and intervals) to be used for auto analysis. In recent time, many techniques signal showing P-QRS-T wave which already offered to identify these features [4]. Initial suggested methods of ECG signal analysis was supported the method of time domain. But that wasn't always sufficient to review the overall features of the signals of ECG that the graphical representation of an indication is extremely much important. The deviations within the conventional electrical pattern in ECG show various forms of cardiac disease. In regular physiology Cardiac cells are polarized electrically [5]. Here ECG is generally accountable for observing as well as diagnosis of patient's condition.

From the ECG signal, the extracted features play a significant role in analyzing the cardiac disease. For automatic feature-extraction of ECG, the event of accurate and quick methods is of main importance. Hence, it's obligatory that the system of feature-extraction executes correctly. To seek out some belongings as possible within the signal of ECG is that the purpose of feature extraction that may permit successful anomaly detection and efficient diagnosis.

The driving philosophy behind the study of ECG signals is discussed in the next section 2. The development of the

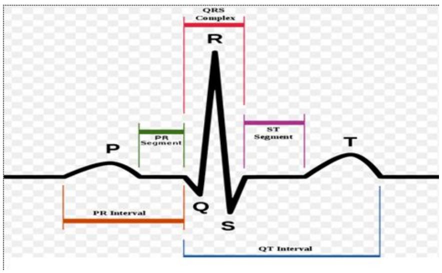


Figure 1. An instance of ECG Signal showing P-QRS-T complex

proposed system and user interface (UI) are discussed in section 3 and Section 4, respectively. In section 5, 6 and 7 discussed experimental results, performance evaluation, and performance comparison, respectively. The conclusion, suggestions and future works are discussed in section 8.

2. DRIVING PHILOSOPHY OF ECG

Biomedical Engineering is an evolving study magnet which has been fascinating scholars. An ECG/EKG is such a project. Maximum physicians and medical employees believe that the ECG/EKG isn't 100% correct as well as occasionally additional tests are run to check any ailment. Moreover it's very problematic for the physicians to manually evaluate each wave with the help of bare eye.

For example, 10 to 20 minutes of nonstop data of ECG is down tested in the result produced in paper, it disturbs the accurateness. On the other hand, the scientists believe that the ECG/EKG is skilled for identifying various irregularities in heart if appropriately examined as well as if the noises are clarified. This is the main dares of our proposal.

Our platform is working on the unceasing dataset from the device of ECG as well as the produced result of ECG. Besides transformation of wavelet also eliminates the noise which guarantees extraordinary accuracy. For the doctors, they don't want to analyses the graph rather they can outlook our properties of wave which decreases a lot of their efforts and lessens the error of human. Maximum stuffs that do test aren't doctors. Consequently they can't identify a few difficulties instantaneously. They forward the printed averaged outcome to the physicians and then the physicians deliver medical clarification and reference which trashes a lot of time for a patient. The proposed developed system may identify ailments founded on the belongings of the ECG wave. Therefore, the patient gets to recognize the heart status when the ECG is completed without visiting a physician which saves lots of time for the patient as well as he/she may still appointment with the physician for expert estimations as well as the proposed program outcome may also suggest wave properties which is helpful for the doctors. The proposed program can be included with the appliance of ECG in the diagnostic centre to deliver exact result, the status of heart as well as wave properties.

3. DEVELOPMENT OF THE PROPOSED SYSTEM

Like other systems, the proposed system comprises the classical pattern recognition components- data acquisition, pre-processing, feature-extraction as well as classification [6]. These components are used in the two primary functional modules of ECG system - the enrolment module and the recognition module. The 2nd module may either work in the mode of verification or in identification [7]. The proposed system is developed for identification mode. Figure 2 illustrates the basic structure of the proposed ECG system. Both phases have some common components.

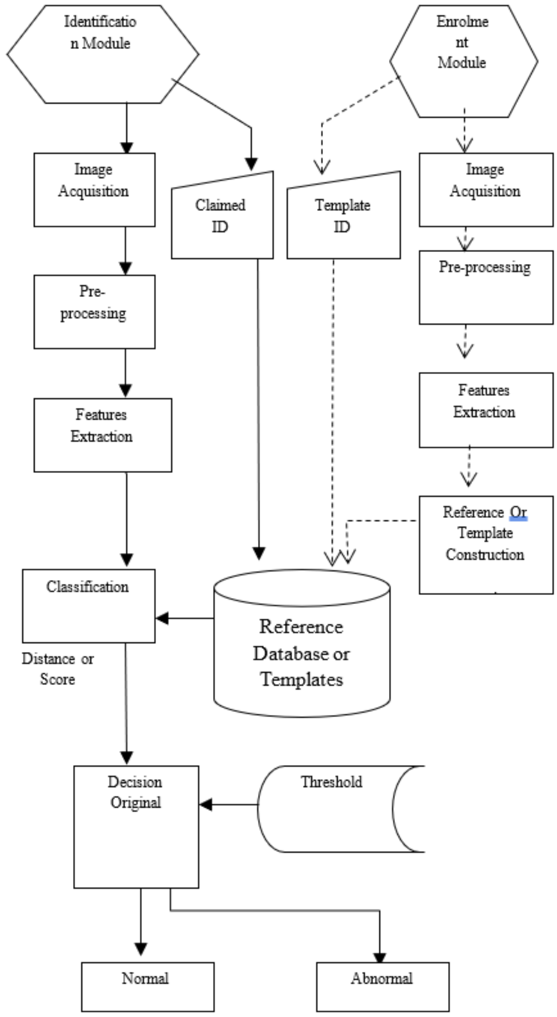


Figure 2. Block Diagram of the Proposed ECG identification System

The enrolment segment comprises of image-acquisition, pre-processing, feature-extraction, template-construction along with construction of the reference database. For the time of enrolment phases, two or more samples have been taken. After features extraction, calculated mean value as well as standard deviation of distinct feature will be used to make the template for each person. The identification phase comprises of image-acquisition, pre-processing, feature-extraction, classification as well as decision. In the time of identification, the data of input is paralleled with the corresponding data of reference. When the user enters their individual identification number, the data of reference is selected from the reference database.

With the purpose of developing the offered system, both hardware as well as software tools are required. The hardware device is simply a mobile. The camera of a mobile is employed to accumulate ECG images. The software tools are: Matlab R2018a for front-end application, Microsoft Access 2010 for backend database support, MS Paint for scaling operation and MS Excel 2010 for data sheets or investigational outcomes analysis.

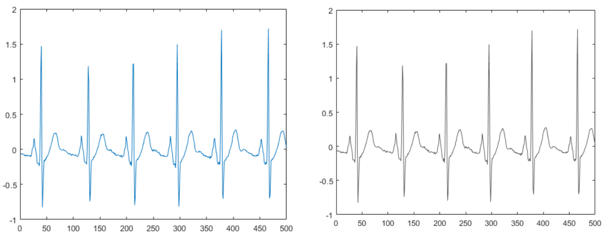
A. Pre-processing

The leading step within the pre-processing is to convert the colour image into gray level image. Then, by employing a threshold value the background noise from the gray level image is eliminated. Then an edge-detection algorithm, supported the Sobel function, is applied to extract.

i. Converting colour image to gray scale image

A colour image comprises of a coordinate matrix additionally three colour channels. Coordinate matrix comprises x, y coordinate values of the image. The colour channels are labelled as Red, Green and Blue. The colour image is converted to gray scale which is shown in Figure 3 using the subsequent equation:

$$GrayColour = (Red + Green + Blue)/3 \tag{1}$$

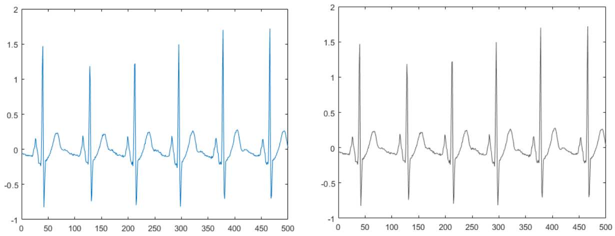


Original Image Gray Image

Figure 3. Colour image to gray scale image conversion

ii. Converting colour image to binary image

A digital image which has simply 2 possible values for each pixel is called a binary image. Naturally, the two colours (black and white) are used for a binary image. The foreground colour is used for the object in the image while the background colour is used for the rest of the image. The colour image is converted to binary using a threshold value which is shown in Figure 4.



Original Image Binary Image

Figure 4. Colour image to binary image conversion

iii. Background-noise elimination

Image with background noise, due to the irregularities within the image scanning in addition as capturing, should be handled for good performance of the system. Gaussian filtering technique is intended for background noise elimination. It is widely utilized in image segmentation. The subsequent figure 5 shows background-noise elimination of a resourceful image.

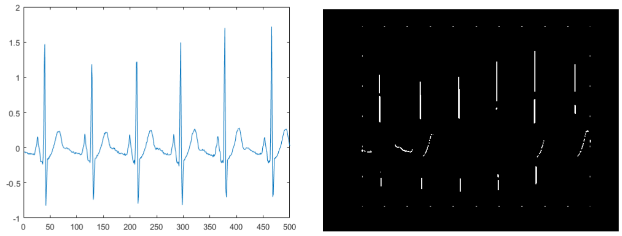


Figure 5. Background-noise elimination of original image

iv. Edge detection

A method of image processing for finding the limitations of objects within images is called Edge detection. It works with identifying incoherence in illumination. It's applied for image -segmentation as well as data-extraction in areas for instance image-processing, machine-vision as well as computer-vision. Its algorithm includes Canny, Prewitt, Sobel, Roberts as well as fuzzy logic methods. It uses Sobel to identify the edges. Edge detection is detected by looking the maximum as well as least in the first derivative of the image. Edge detection is involved in these subsequent steps:

- **Smoothing:** Without dismissing true edges, overcome as much noise as probable.
- **Enhancement:** To develop the distinction of edges (i.e., sharpening), apply differentiation.
- **Thresholding:** Express edge pixels which must be excluded as noise as well as which must be reserved (i.e., threshold edge magnitude).
- **Localization:** Define the exact edge location sub-pixel resolution might be requisite for some claims to evaluate the location of an edge to better than the spacing between pixels.

B. Feature extraction

For the purpose of identification, we have to extract various features from the ECG data which is pre-processed, comprising P wave, QRS wave, PR intervals, ST intervals and so on. The most noticeable feature here is QRS wave as well as the correct recognition of QRS wave forms the beginning for the extraction of other features. The aim of the process of feature-extraction is to choice as well as removes analytical info from the original signal of ECG. Moreover seeks limited properties as probable within the ECG signal that could permit successful abnormality finding. To extract features, Wavelet Packet Transform has been used in this paper.

i. Wavelet selection

A number of methods are established by the scholars to identify the properties in ECG. For Non-stationary signal analysis, recently wavelet transform has been recognized to be an appropriate tool [8].

A wavelet is sometimes a tiny wave which is comparable to vacillation with amplitude that starts at zero, rises, and then declines back to zero [9]. In place of a mathematical tool, it's used for extract information from numerous styles of data. The conception of wavelet transform founded on the processing of signal yet as advanced from the basis of Fourier Transform. In function, Wavelet transform (WT) might be a direct unification of wavelet basis function in an actual real space. It operates on the linear operation of signal moreover as basis function. It has become an efficient as well as attractive tool in numerous applications especially in coding yet as firmness of signals for Multi-resolution in addition high energy compaction properties [10]. The WT is expected to discourse the matter of non-stationary signals. It includes indicating a time function in terms of straightforward, static building blocks correspondingly as called wavelets. These building blocks are accurately a clan of functions that are resulting from one creating function termed as the mother wavelet by interpretation as well as dilation procedures.

Dilation is understood as scaling, stretches or compresses the mother wavelet as well as translation shifts it along the axis of time. Due to the flexibleness, it offers in analysing basis functions; the employment of the WT has gained admiration in analysis of time frequency. The assortment of wavelet relies on the fashion of signal to be evaluated. The wavelet is equivalent to the signal which is generally selected. Among the lasting methods of wavelet alike continuous, dyadic, orthogonal, bi-orthogonal, we select wavelet transform of real dyadic. It's appreciations to its noble sequential localization belongings equally as its fast calculations. Daubechies Wavelet has been found to provide fine points more correctly than others. Furthermore, this Wavelet displays likeness with QRS waves also as energy spectrum is decided around low frequencies. For that reason, Daubechies (Db4) Wavelet has chosen in this proposed application for extracting features of ECG. The Daubechies Wavelet is shown in Figure 6, Figure 7 and Figure 8.

ii. PQRST detection

The QRS wave is the amalgamation of three of the pictorial deflections (Q, R and S waves) displayed on a usual ECG

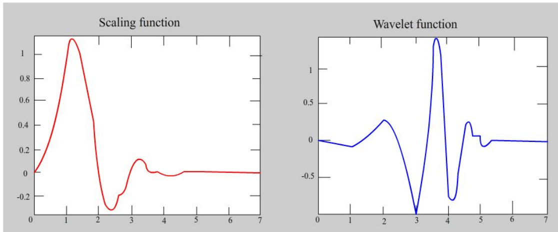


Figure 6. Wavelet packet transform

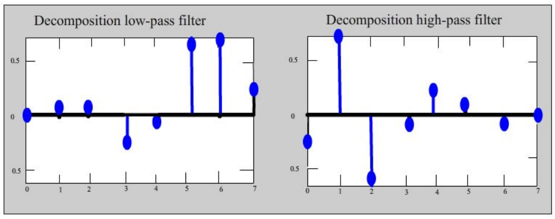


Figure 7. Wavelet packet decomposition

signal. It is the best prominent waveform within the ECG. In case of noisy signal not every QRS wave comprises a Q wave, an R wave as well as an S wave. Later eliminating the noise from the ECG signal, the extreme peaks which symbolize the R-peaks have been found. Nevertheless, several peaks are right near to each other, the R-peaks have been identified by threshold to eliminate undesirable peaks. Formerly, the smallest rate in a window of the R location-20 to the R location-2 has been chosen to determine the locations of the Q-waves. Afterward, peak recognition on the genuine signal has been accomplished as well as used rational indexing by smearing window of R location+2 to the R location+20 to determine the positions of the S-waves.

There would be a P-wave preceding each QRS wave in sinus rhythm. The space for the P-wave is designated by beginning from R location -80 to the R location -15. The T-wave symbolizes the voltage repolarization effect after ventricular depolarization. Repolarization is minor than depolarization; consequently, the T wave is further spread out as well as has a lower amplitude (height) than the QRS wave. The window for the T-wave is designated by beginning from R location +25 to the R location +140.

The waves of P and T exist in one R-R interval, P-waves exist closer to the 2nd R-peak in one R-R interval, as well as T waves lie next to the 1st R-peak. The particular P and T peak location is labelled by entrancing the maximum value in their respective windows. The following Figure 9 shows that the PQRST successfully detected in the ECG signal.

- **R-R Interval:** The difference between R-peaks is called R-R Interval. It is used clinically as a sign of Ventricular Heart Rate. Its metrics are produced from the deflection positional information. To define R-R interval, two R peaks in consecutive beats is computed as well as their difference is calculated using the subsequent formula:

$$R-R(i) = RLoc(i+1) - RLoc(i) \quad (2)$$

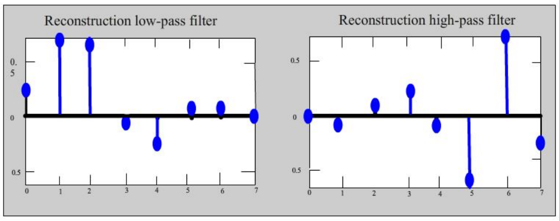


Figure 8. Wavelet packet reconstruction

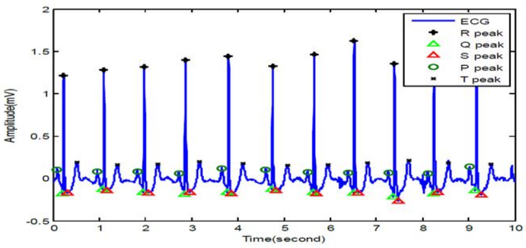


Figure 9. PQRST detection

where R peak locations is represented by *RLoc*.

- **P-R Interval:** The difference between the location of R peak and P peak, is symbolized by PR, is calculated using the subsequent formula:

$$P-R(i) = RLoc(i) - PLoc(i) \tag{3}$$

Where R peak locations are denoted by *RLoc* and P peak locations are denoted by *PLoc*.

- **QRS Interval:** QRS interval is computed by the subsequent formula:

$$QRS(i) = (SLoc(i) + x) - (QLoc(i) - x) \tag{4}$$

Where S and Q peak locations are represented by *Sloc* and *Qloc* respectively, x signifies instant 5 ms, these examples are supplementary for *Sloc* as well as are deducted from *Qloc* as the duration of QRS is cleared from the start of Q peak till termination of S peak.

- **Heart Rate:** The R-R interval is being is depended on the Heart Rate, the R-R interval has been used to compute the heart rate as in the subsequent equation:

$$Heart-Rate = (60/R-R\,Interval)\,beats\,per\,minute \tag{5}$$

The feature-extraction from ECG signal is shown in Figure 10.

4. DEVELOPMENT OF USER INTERFACE

In MATLAB platform, a user friendly interface was established for examine the signal of ECG for identification in 'Normal' or 'Abnormal'. The database of ECG signals at

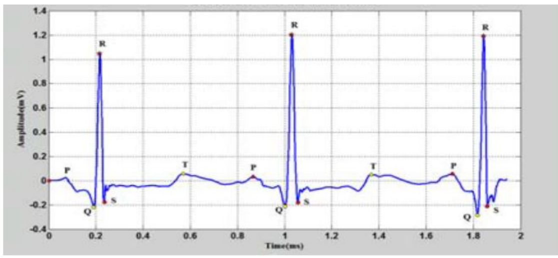


Figure 10. Features extracted from ECG signal

home with estimate the entire act of the system solicitation for recognition of arrhythmia in an exceedingly patient.

The user interface (UI) is desired to contain:

- To show the original signal and pre-processed signal of ECG, Two figure windows are used.
- For the pre-processing tasks as well as classification, Static text components are used.
- Static buttons which allows various sorts of tasks of pre-processing.
- Push buttons that offer the loading of ECG signal, choice of type of pre-processing task, identify the signal, clearance of unique as well as processed signal of ECG, and departure from the UI environment.

In MATLAB, the application is applied on an ASUS system with Intel ®Core i3, running MATLAB version (R2018a) on 64-bit Windows 10 software package. The application isn't standing alone and may only be titled and implemented in the environment of MATLAB.

5. EXPERIMENTAL RESULTS IN IDENTIFICATION

Experimental results are discussed in the subsequent section 5.1 and 5.2.

A. The Developed User Interface

The outline of the MATLAB based developed UI for the application is displayed in Figure 11.

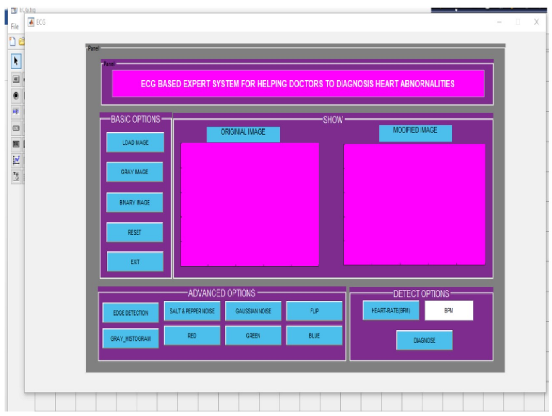


Figure 11. The developed MATLAB based UI layout for the Computer-aided ECG analyze

The UI contains:

- With axes component, two figure windows is used. The uploaded waveform of ECG is displayed by the left window, while the proper window shows the waveform of the processed signal.
- To label the name of the system, a static text component is used. Again, to label the heart rate result display, a static text component is also used.
- Ten buttons that offer the various styles of pre-processing jobs.
- Five buttons that offer the loading of the signal of ECG from the database formatted records of ECG; implementation of the chosen sort of pre-processing job to be allotted on the signal of ECG; detecting the signal of ECG; dissipating of both uploaded as well as processed signal of ECG; and then departure from the environment of UI.

B. Operation of the UI

From MATLAB, upon beginning the application, the UI shows on the pc screen. Clicking on the "Load Image" button, the application proceeds the manipulator to the database folder of ECG from which the manipulator selects the record to be showed. Having selected the record of ECG within the database, the left figure window shows the chosen signal of ECG in type of a plot, using an in-built specified plot.

To identify the signal, the manipulator should do all the tasks of pre-processing by clicking the corresponding push buttons one after the other.

Failure to take on the tasks of pre-processing will outcome in improper identification. Correspondingly, no pre-processing job must be implemented fairly once as this may moreover outcome in improper diagnosis. The correct figure window shows the waveform plot of the consequences of every phase of the pre-processing on the input signal of ECG.

Clicking the "Diagnose" button supports the application to identify the signals of ECG whichever being 'Normal' or 'Abnormal' with conforming attendant message or see. The subsequent messages are showed looking on the results of analysis.

- If normal, then notice: "No heart problem". Performance Result: "NORMAL: No Arrhythmia detected in Patient".
- If abnormal, then notice: "There is Heart Problem!" Performance Result: "ABNORMAL: Arrhythmia detected in Patient".
- If signal is distorted or too corrupted, then notice: "UNKNOWN Signal!" Performance Result: "UNKNOWN Signal is Unclassifiable".

Figure 12 displays the developed system that displays the test and diagnosis of an abnormal ECG signal with results of diagnosis indicating the problem of heart.

The features of the assorted signal which found by these studies are briefing in Table 1 for small number of signal. Irregularities of these signals are displayed by Italic Underline.

Figure 12. UI display of an ECG signal, processed and diagnosed to be abnormal

6. PERFORMANCE EVALUATION

The complete performance of the established application is valued by five statistical indices: Accuracy (*ACC*), Sensitivity (*Se*), Detection error rate (*DER*), Specificity (*Sp*) and Positive Predictivity (+*P*) [10]. All of these metrics depend on the computations that display how good a classifier is in identifying true positives (TP -class detected is actually the real class) as well as true negatives (TN- e.g. QRS wave isn't stated when there is no one in the signal of testing) and then simultaneously susceptible to errors of false positives (FP- i.e. abnormal ECG classified as normal) as well as false negatives (FN-i.e. normal ECG classified as abnormal). The established application was verified with the self-collected archives. From the test carried out by the application, TP = 60, TN = 54, FP = 3, and FN = 3. Accuracy (*ACC*) calculates the general performance over all types of beats. It's the proportion of properly classified patterns to the complete number of patterns classified, and is calculated by using equation (6).

$$ACC(\%) = \frac{TP+TN}{TP+TN+FP+FN} \times 100\% \tag{6}$$

$$ACC(\%) = \frac{60+54}{60+54+3+3} \times 100\% = 95\%$$

Sensitivity (*Se*) is that the proportion of appropriately classified event among all accurate events. Therefore, it measures the accuracy in detection and is calculated by using equation (7).

$$Se(\%) = \frac{TP}{TP+FN} \times 100\% \tag{7}$$

$$Se(\%) = \frac{60}{60+3} \times 100\% = 95.23\%$$

Specificity (*Sp*) is that the proportion of the amount of accurately rejected non-events, TN (true negatives), to the full number of non-events. Therefore, it gives a suggestion of refusal of false identifications and is calculated by using equation (8).

$$Sp(\%) = \frac{TN}{TN+FP} \times 100\% \tag{8}$$

Table 1. Experimental Results for the different extracted features of ECG signal

Feature	Normal range	Record 01	Record 02	Record 03	Record 04	Record 05	Record 05	Record 06
Heart-rate (beat per minute)	60-100	73.83	77.09	72.28	67.16	*56.39*	97.09	*121.9*
R-R interval (sec)	0.6-1	0.86-0.95	0.83-0.94	*0.52-1.32*	0.94-1.0	*1.17-1.26*	0.59-0.70	0.36-0.73
P peak	Present, upright	Normal	Normal	*Some are absent*	P peak amplitude very low	*Absent*	*Absent*	Present, Amplitude, Very low
P-P interval (sec)	0.6-1	0.86-0.94	0.83-0.93	*0.44-1.43*	*0.98-1.18*	-	-	0.23-0.80
P-R interval (sec)	0.12-0.2	0.12-0.14	0.13-0.17	0.13-0.2	*0.15-0.42*	-	-	*0.09-0.27*
QRS interval (sec)	0.06-0.1	0.08-0.12	0.04-0.1	*0.05-0.19*	0.1-0.16	0.075-0.12	*0.014-0.13*	*0.08-0.20*
S-T interval	0.05-0.15	*0.19-0.25*	*0.17-0.26*	0.02-0.14	0.19-0.13	*0.31-0.35*	*0.2-0.26*	0.12-0.15
Disease	None	*Myocardial injury*	*Myocardial injury*	*PVC, Myocardial injury*	*Myocardial injury*	*PVC*	*PVC VT*	*PVC VT*

$$Sp(\%) = \frac{54}{54+3} \times 100\% = 94.7\%$$

Detection error rate (*DER*) is calculated by using equation (9).

$$DER(\%) = \frac{FP+FN}{TP+FN} \times 100\% \quad (9)$$

$$DER(\%) = \frac{3+3}{60+3} \times 100\% = 9.5\%$$

Positive Predictivity (+*P*) is that the proportion of the amount of accurately identified events, TP represents the entire number of events identified. In this application, (+*P*) represents the possibility that the outcome of test is ‘Normal’ when the disease is absent. It is calculated by using equation (10).

$$+P(\%) = \frac{TP}{TP+FP} \times 100\% \quad (10)$$

$$+P(\%) = \frac{60}{60+3} \times 100\% = 95.23\%$$

Consequently, the possibility that there is no heart disease when the outcome of identification by the application shows ‘Normal’ is 95.23%.

7. PERFORMANCE COMPARISON

The relative comparison is made based sensitivity and on specificity. The final outcome of detection is delivered in Table 2.

Table 2. Sensitivity and Specificity compared with previous work.

Approaches	Sensitivity	Specificity
Proposed model	95.23	94.7
M.Umer et al[11]	96.9	92.59
Mohammad et al.[3]	99.18	98

By comparing the outcomes of the offered algorithm with M. Umer *et al.* [11], it is noticed that the offered model had an improvement within the values of sensitivity as well as specificity. Besides, the offered algorithm is additionally easier to implement while Castro et al. [12] is complex as well as need enormous computation time.

The performance of the offered model is further compared with the prevailing work by measuring the accuracy of the classification. Table 3 is provided with classification accuracy of the proposed model.

Table 3. Measurements of classification accuracy based on ECG signals.

Disease	Training Data	Testing Data	Misclassification	Classification Accuracy (%)
Sinus bradycardia	20	15	1	93.33
Sinus tachycardia	25	20	1	95.00
Myocardial injury	15	10	1	90.00
Atrial Fibrillation	20	22	1	95.45
Atrial Flutter	40	35	2	94.28
Total	120	102	6	94.12

It is noticed that the performance of the proposed system is that the best among all prevailing systems. The utmost classification success of the prevailing systems is 96% [13]. On the opposite hand, the proposed system offered 95.45%.Though the accuracy of proposed system is less than the prevailing system, but the proposed system is best because of working numerous features more than the prevailing system.

8. CONCLUSION AND SUGGESTIONS

As a conclusion here, computerized data capturing as well as sending system built on digitized ECG image have been established. Such computerization system specifically for medical purpose is very significant and obligatory for telemedicine purposes. This is because it enables the patient observing process using the clinical devices without any wire connections. In this project, the output of the developed program will be a self-generated report which containing the patient's information and the heart rate. It will then be send using the internet connection to the user's recipients.

The technology of Patient Observing System (POS) with practices in real-time observing of ECG for the advantage of humanity is deliberated in this paper. Recognition of various features of the signal of ECG is significant for identification of innumerable diseases correlated to heart. The elementary characteristic of the signal in feature-extraction along with interpretation is sensitivity, predictability and low complexity. An expert system with necessary feature-extraction of ECG is an authentic dare in ECG observing systems are keeping increased security; enhance scalability, less complexity and user friendliness.

Additional work is in improvement to increase the complete proficiency of the method as well as developing a proficient system which may help a physician in diagnosis and then producing automatic analysis reports as well.

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