International Journal of Engineering and Technology Vol. 1, No.3, August, 2009
ISSN: 1793-8236

A Rule-based Expert System for ECG Analysis

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***Abstract*—This paper presents the development of a rule-based expert system that emulates the ECG interpretation skills of an expert cardiologist. The knowledge of an expert is confined to him and is not freely available for decision-making. An expert system is developed to overcome this problem. In this rule-based expert system, patient's heart rate and the wave characteristics of the ECG are considered. With these 'facts', rules are framed and a rule base is developed in consultation with experts. An inference engine in the expert system uses these inputs and the rule base to identify any abnormality in the patient's heart. A unique feature of the proposed system is storing the post diagnostic information in a database. That is, information about a patient diagnosed by this system is stored and can be retrieved later date-wise. The user can also input his comments or suggestions for improvement or correction, which can later be incorporated in the system after validation by experts. Only authorized access to the database is permitted. This expert system can support physicians in their diagnosis and decision-making.**

***Index Terms*— ECG, Entity-Relationship diagram, Expert system, if-then-else rules, inference engine, rule-based system.**

I. INTRODUCTION

Heart disease has become the most common disease that affects humans worldwide. Each year millions of people die from heart attacks and an equal number undergo coronary artery bypass surgery or balloon angioplasty for advanced heart disease [1]. Early detection and timely treatment can prevent such events. This would improve the quality of life and slow the progression of heart failure. The first step in the diagnosis is to record the ECG of the patient. An ECG record is a non-invasive diagnostic tool used for the assessment of a patient's heart condition. The features of the ECG, when recognized by simple observations, and combined with heart rate, can lead to a fairly accurate and fast diagnosis [2].

Nikos E. Mastorakis et al [3] have developed an expert system for ECG Analysis that works by hierarchically organizing the knowledge in a context tree. A disease is recognized by traversing the tree that has symptoms of the disease as the nodes and the disease as the leaf nodes. Sanjay M. Patil et al [4] have used time and frequency

domain parameters and correlation constants derived from ECG signals as inputs for their expert system.

They have used Turbo C for analysis and Turbo Prolog for diagnosis. Hamilton P [5] has developed a software for ECG beat detection and classification and made available as an open source system for use by researchers. Andreao et al [6] have proposed a technique for analyzing ECG signals using hidden Markov models for beat segmentation and classification. Silipo R and Marchesi C [7] have explored the use of neural networks for automatic ECG analysis for the classification of different cardiac abnormalities. Each of the above mentioned approaches have their merits and applications. The proposed expert system is a rule-based decision support system to aid physicians in the diagnosis of heart diseases. This is standalone software and can be easily implemented on a PC.

In the proposed system the user needs to input the wave features as seen in the ECG of a patient. These are used to identify the rule from an already established rule-base for diagnosis by the system. The post diagnostic results are stored in a database date-wise for future reference. The expert system also accepts comments from the user which can be incorporated in the system after validation by experts. Built using Visual Basic, this expert system provides a very simple and friendly user interface.

The work presented in this paper is organized as follows. Section II describes the methodology of the proposed system. Section III discusses the implementation details of the system. Section IV illustrates the use of the developed system. System testing is explained in Section V and conclusion is presented in Section VI.

II. METHODOLOGY OF THE PROPOSED SYSTEM

The block diagram of the proposed system is shown in Fig.1. The framework of the rule based expert system [4] consists of

1) facts – input obtained from the user's response through the graphical user interface based on observations from ECG
2) a rule-base – a set of rules developed in consultation with experts based on heart rate and ECG wave characteristics
3) an inference module – that matches the input (facts) with a rule in the rule-base to identify the abnormality [2]
4) a database – that stores the patient's personal details, inputs, diagnosed results and user's comments / suggestions

Expert cardiologists were consulted and rules were framed with patient's heart rate and ECG wave characteristics as inputs [8]. An easy to use graphical user interface (GUI) is provided for the user to enter the patient's personal details, heart rate and select wave characteristics based on the ECG of the patient. When these inputs are submitted to the system for analysis, the inference engine identifies the rule that best

Manuscript received June 10, 2009.

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satisfies the inputs and displays the associated abnormality. The user can also input his comments / suggestions. The inputs, diagnostic results of the patient and the user's comments / suggestions are stored in a database date-wise for future reference. Existing rules and the associated abnormalities can be modified and new rules can be included through authorized access to the database. Rules are framed with the features and the associated abnormality. Rules existing in the system can also be viewed using the navigation buttons provided. Access to the database is secured by means of password. Provision to change the password is also included. A dataflow diagram of the proposed system is shown in Fig. 2

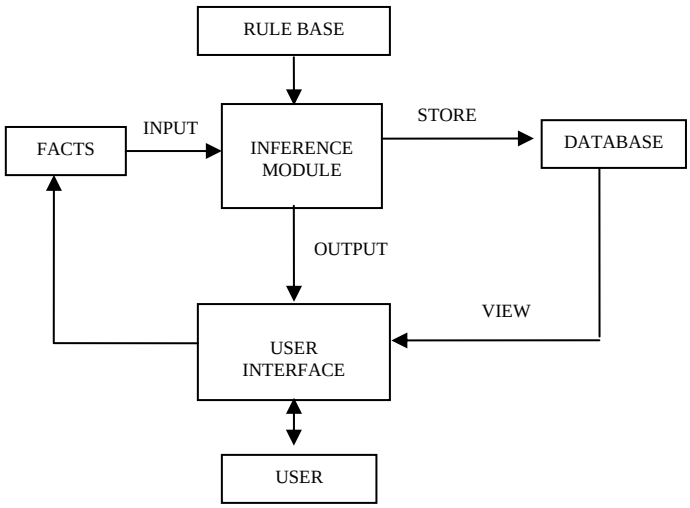

Fig.1. Proposed System

III. IMPLEMENTATION

The implementation of the expert system begins with the creation of a database that has several tables. The Entity-Relationship diagram of the proposed system is shown in Fig.3

The various tables of the database are described in the following paragraphs and the corresponding layouts are shown in Table I through Table IX.

Patient Details Table

The patient details table is as shown in Table I. In this table, patient's identification number (ID), name, age, gender and address are stored. The patient ID is the unique key to identify a patient and view stored details of the patient.

TABLE I PATIENT DETAILS

Patient_Details				
Patient_Id	**Patient_Name**	**Age**	**Gender**	**Address**
1001	Lakshmi	47	Female	Coimbatore
1002	Periyanayaki	45	Female	Chennai
1003	Meenakshi	43	Female	Salem
1004	Ramachandran	51	Male	Trichy

Patient Visit Table

The patient visit table is as shown in Table II. This table holds the diagnostic results of a patient (diagnosed by the system) date wise. The details include patient ID, date of visit, diagnosed abnormality and user's comments.

TABLE II PATIENT VISIT

Patient_Visit			
Patient_Id	**Date_Of_Visit**	**Abnormality**	**Comments**
1001	11/28/2008 10:49:44 AM	Acute Coronary Insufficiency-Angina pectoris	Accurate
1002	11/28/2008 10:51:35 AM	Atrial Fibrillation	Nil
1003	11/28/2008 10:53:06 AM	Sinus Arrhythmia	Additional feature required

Rule base table

The rule base table is as shown in Table III. This table holds the heart rate and ECG features and the associated abnormality. The ECG features include the wave features of P, Q, R, S, T waves and additional features interpreted from the ECG [10],[11]. Count specifies the total number of features for an abnormality including heart rate and it is incremented or decremented automatically when a feature is added or deleted.

TABLE III RULE BASE

Abnormality	**Heart Rate**	**Feature 1**	**Feature 2**	**Feature 3**	**Feature 4**	**Count**
Atrial Fibrillation	200	Irregular RR interval	P waves not visible	Fibrillatory waves visible in V1		4
Sinus Arrhythmia	75	Rhythm irregular	P wave normal	PR interval normal	PP interval variable	5

P, Q, R, S and T tables

These tables hold description of features of the respective wave currently entered in the expert system and are updated when features are added / edited. During ECG analysis the description of the features are retrieved from these tables and displayed in the GUI. The user chooses the appropriate features as interpreted from the patient's ECG.

Table IV P_Wave

	P_wave
p1	P wave absent
p2	P in L2(>2.5)(Pulmonale)
P3	P wave is altering gradually
p4	P wave normal

TABLE V Q_WAVE

	Q_wave
q1	Q wave in L2,3,AVF,V5,6
q2	Insignificant Q in L1,AVL

q3	Deep Q in V2-6,AVL
q4	Q in L2,3,AVF

TABLE VI R_WAVE

	R_wave
r1	Tall R in V1,V2
r2	Slurred R in V1
r3	Broad slurred R in V6
r4	Tall R in V1-2

TABLE VII S_WAVE

	S_wave
s1	Slurred S in L1,V6
s2	Deep S in L3,AVF
s3	Deep S in V1
s4	S in L1 and V1-6

TABLE VIII T_WAVE

	T_wave
t1	T wave inversion in L1,AVL,V4-6
t2	Peaked T waves upright in V1,V2
t3	Biphasic T in L2,3,AVF,V5,6
t4	T inversion in most of the leads

TABLE IX OTHER WAVES

	P,Q,R,S,T_Combinations
	Other waves
ow1	Q T 0.36 sec
ow2	ST-T changes are significant
ow3	ST depression in L1,AVL,V4-6
ow4	ST elevation

TABLE X OTHER FEATURES

	Other Features
of1	Left Axis Deviation
of2	Artial rate 320/minute
of3	Ventricular rate 130/minute
of4	Minimal elevation in L2,V5-6

This PC based medical expert system has been developed using Microsoft Visual Basic 6.0 for the user interface and Microsoft Access for the database. The Data Access Object (DAO) has been used to connect MS Access with Visual Basic. The platforms supported are Microsoft Windows XP/Vista. An executable file has been created for portability.

IV. ILLUSTRATION

Illustration 1:

- Consider the patient with id 1002 in Table II. The diagnosed abnormality is 'atrial fibrillation'. Now row1 in the rule base table (Table III) shows the heart rate and the three features that should have been selected for the inference engine to identify the abnormality as atrial fibrillation.
- During ECG analysis the heart rate is entered in a text box and the ECG features are chosen from the combo boxes.
- If the heart rate is not entered match will not occur in this case because heart rate is one of the necessary inputs for this rule.
- If the heart rate is entered, the value can range between ±5 from the actual heart rate in the rule base table.
- The selected ECG features are now compared with the rule base.
- If all the four features are selected correctly, the rule matches with the first row in Table III, and the system displays the abnormality as "Atrial Fibrillation".
- If the ECG features selected do not match any rule, the message "no matching rule found" is displayed.
- The physician is prompted to enter his comments, which is optional.
- The diagnostic results are stored in the database and can be retrieved for reference in future.

The screen image of the proposed expert system corresponding to this illustration is shown in Fig. 4.

Illustration 2:

- Consider the patient with id 1003 in Table II. The diagnosed abnormality is 'Sinus Arrhythmia'. Now row 2 in the rule base table (Table III) shows the heart rate and the four features that should have been selected for the inference engine to identify the abnormality as Sinus Arrhythmia.
- During ECG analysis the heart rate is entered in a text box and the ECG features are chosen from the combo boxes.
- If the heart rate is not entered match can still occur in this case because heart rate is not a necessary condition for this rule.
- The selected ECG features are now compared with the database.
- If all the five features are selected correctly, the rule matches with the second row in Table III, and the system displays the abnormality as 'Sinus Arrhythmia'.
- If the ECG features selected do not match any rule, the message "no matching rule found" is displayed.
- The physician is prompted to enter his comments, which is optional.
- The diagnostic results are stored in the database and can be retrieved for reference in future.

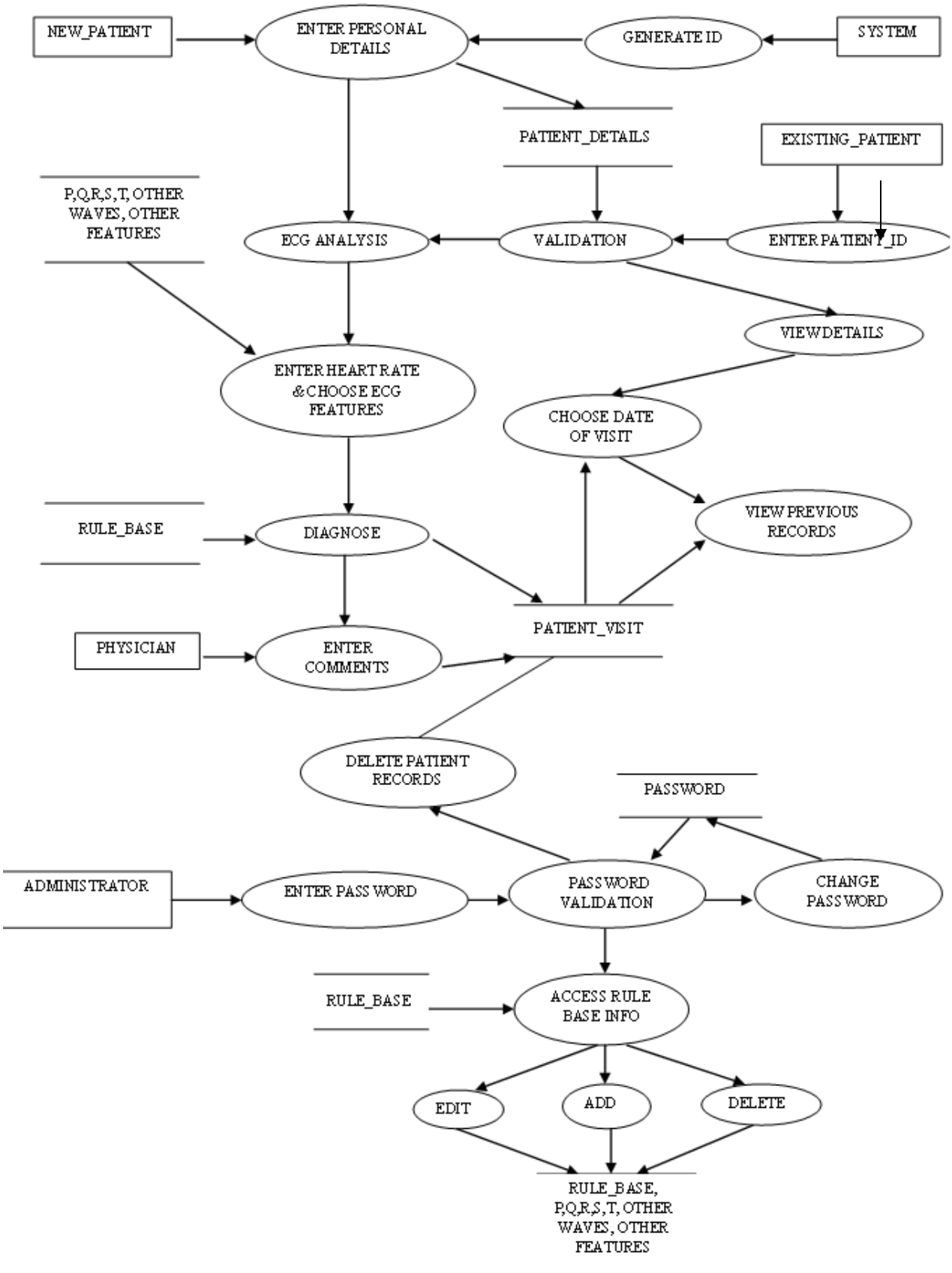

Fig 2. Data Flow Diagram

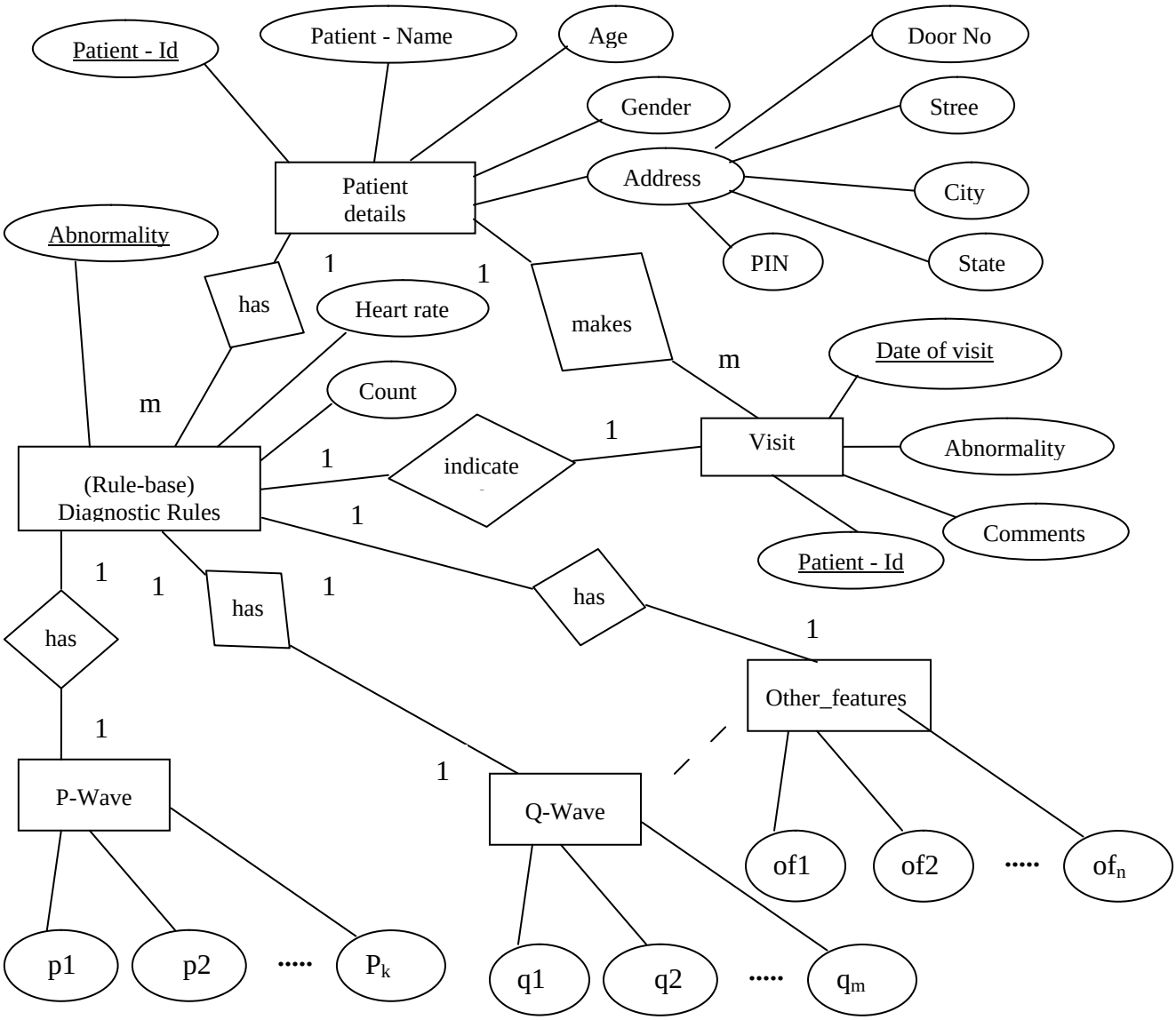

Fig 3. E-R Diagram

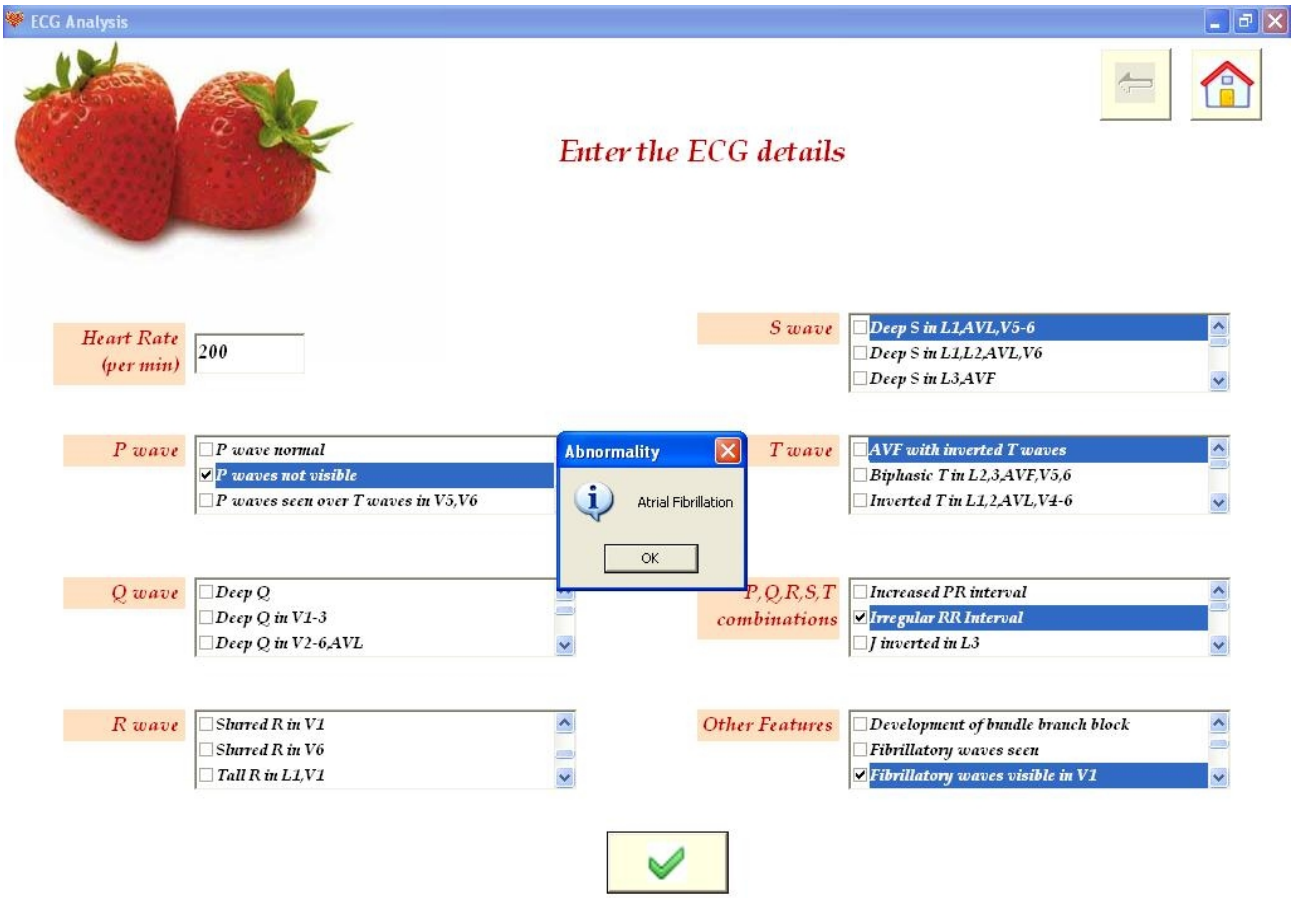

Fig. 4. Screen image of the system for illustration -1

V. Testing

The complete set of rules initially input to the system has been checked. This expert system was submitted to medical experts for their validation. Addition and modification of rules suggested by them have been incorporated. Whenever any modification or inclusion of a rule was made, all the rules were again thoroughly checked.

The validation results obtained from experts are presented in Table XI.

Table XI Results

Expert	No of patients diagnosed	Abnormality satisfactorily detected	Diagnostic accuracy (%)
1	90	88	97.78
2	75	72	96.00
3	60	58	96.67

VI. Conclusion

A rule-based expert system for ECG analysis has been developed. The developed system is not a substitute for a physician. A physician's diagnosis is the most valued. Since the knowledge of an expert remains confined to him, an attempt has been made to build this expert system to emulate the interpretation skills of the expert. Patient's heart rate and ECG features were used as inputs to the system for analysis and identification of any abnormality. The highlights of the proposed system include (i) storage of patient's personal details, user's input, analyzed results, user's comments date-wise in a database. The stored information can be viewed date-wise. (ii) authorized access to the rule-base permitting addition, modification and deletion of rules. The rules used in this system were developed in consultation with experts. These rules are always subject to change as medical knowledge improves; thus it is necessary to periodically update the rule-base [8],[9],[12]. The developed system can aid the physician in the diagnosis of heart diseases.

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