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IOT-BEAT: An Intelligent Nurse for the Cardiac Patient with Music Therapy

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Abstract - *Cardio-vascular diseases (CVDs) are the number 1 cause of death globally. More people die annually from CVDs than from any other cause. An estimated 17.7 million people died from CVDs in 2015, representing 31% of all global deaths. Of these deaths, an estimated 7.4 million were due to coronary heart disease and 6.7 million were due to stroke. Greater than 75% of CVD deaths occur in low-income and middle-income countries. 80% of all CVD deaths are due to heart attacks and strokes. In India alone, there are around 64 million cardiac patients and only 4000 cardiologists available. Arrhythmia is the most frequently occurring CVD. Patients having Arrhythmia require continuous monitoring so that the doctor can study the abnormality in their heartbeats to gain further insights and suggest treatments. In some cases, Arrhythmia can be fatal and might need immediate hospitalization. For this purpose, we have developed a system that remotely acquires ECG sensor readings (taken from MIT-BIH database) of the patient as well as from the human body, processes it to predict arrhythmia intelligently and sends an indication alarm immediately to the doctor. Simultaneously, the music in appropriate classical musical ragas will be played on the smartphone of the cardiac patient automatically to control an arrhythmia temporarily (that means to reduce heart rate up to normal range).*

***Key Words*: signal processing, Internet of Things (IoT), electrocardiogram (ECG), GSM technology, remote monitoring, music therapy.**

1. INTRODUCTION

Arrhythmia is the most frequently occurring CVD. Arrhythmia means an abnormal rate of heart contraction which is dangerous as it may also cause death. Patients having Arrhythmia require continuous monitoring so that the doctor can study the abnormality in their heartbeats to gain further insights and suggest treatments. In some cases, Arrhythmia can be fatal and might need immediate hospitalization. For this purpose, we are in the process of developing a system that remotely acquires ECG sensor readings of the patient (taken from MIT-BIH database as well as from human body), processes it to predict arrhythmia intelligently and sends the indication alarm immediately to the doctor, when an Arrhythmia episode is detected.

Simultaneously, we are developing an android application such that whenever an Arrhythmia episode is detected, the appropriate music (in appropriate musical *ragas*) will be played automatically from the smartphone of a patient via that android application. Our system aims at alerting the doctor in case of emergencies along with playing music to control an Arrhythmia temporarily (till the time when doctor reach for help).

1.1 Background study

Early models consisted of a monitoring box with a set of electrode leads which attached to the chest. The first wireless electrocardiogram (ECG) heart rate monitor was invented in 1977 as a training aid for the Finnish National Cross Country Ski team and as 'intensity training' became a popular concept in athletic circles in the mid-80s, retail sales of wireless personal heart monitors started from 1983.

In old versions of the monitor, when a heartbeat is detected a radio signal is transmitted, which the receiver uses to determine the current heart rate. This signal can be a simple radio pulse or a unique coded signal from the chest strap; the latter prevents one user's receiver from using signals from other nearby transmitters. Newer versions of the heart rate monitor include a microprocessor which is continuously monitoring the ECG and calculating the heart rate and other parameters. Modern heart rate monitors usually comprise two elements: a chest strap transmitter and a wrist receiver or mobile phone (which usually doubles as a watch or phone). In early plastic straps, water or liquid was required to get good performance.

Later units have used conductive smart fabric with built-in microprocessors which analyse the ECG signal to determine heart rate. There are a wide number of receiver designs, with various features. These include average heart rate over exercise period, time in a specific heart rate zone, calories burned, breathing rate, built-in speed and distance, and detailed logging that can be downloaded to a computer. The receiver can be built into a smart-watch or smartphone. Bracelets with integrated sensors work optically and have poor accuracy.

1.2 Main Contribution

Heart rate is a very vital health parameter that is directly related to the soundness of the human cardiovascular system. There are many systems available which are used to calculate heart rate of a patient and send an alert message to the doctor. Our system also calculates heart rate efficiently and sends an indication to the doctor.

The main contribution is the use of music therapy in our project. There is hardly any system which integrates Music therapy. "Music is therapy. Music moves people. It connects people in ways that no other medium can. It pulls heartstrings. It acts as medicine". Music therapy is a form of healing that uses music to provide care to patients, in a manner that is outside of the box. Therapists use music therapy in a variety of ways, including having people sing along to the music, meditate and relax while music plays and conduct various exercises and movements with music as the catalyst. When played in conjunction with a person's thoughts or movements, music therapy can help to improve everything from a patient's speech to their memory and physical balance. It also provides emotional healing, helping people to develop positive self-image and aids in prioritizing stress and pain.

1.3 Functional units of the device

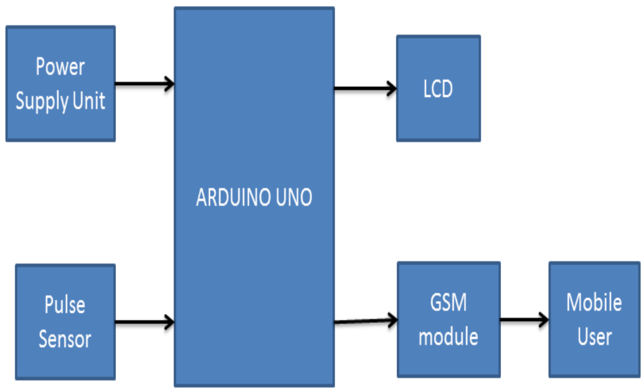

Fig -1: Block Diagram of the Device

A. The Arduino Uno Board

It's an open-source physical computing platform based on a simple microcontroller board and a development environment for writing software for the board. Arduino Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started.

B. The Pulse Sensor

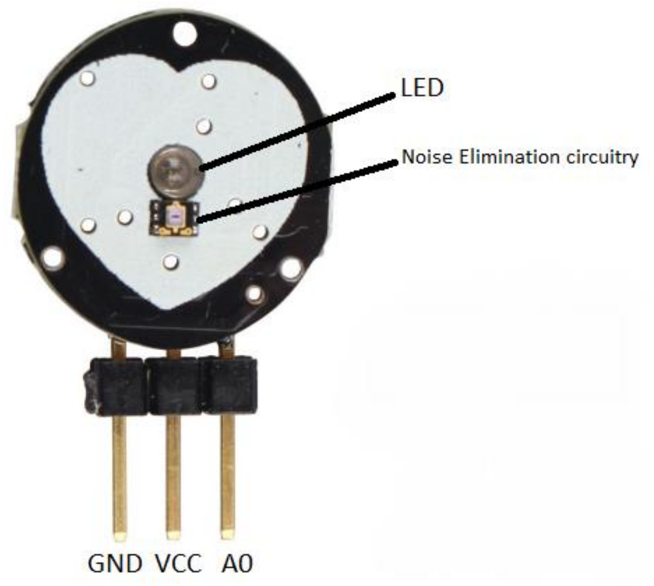

Fig -2: Pulse Sensor – Pin Out

A Heartbeat sensor is a monitoring device that allows one to measure his or her heart rate in real time or record the heart rate for later study. It provides a simple way to study the heart function. This sensor monitors the flow of blood through the finger and is designed to give a digital output of the heartbeat when a finger is placed on it. When the sensor is working, the beat LED flashes in unison with each heartbeat. This digital output can be connected to the microcontroller directly to measure the Beats per Minute (BPM) rate. It works on the principle of light modulation by blood flow through finger at each pulse. The Pulse Sensor is a well-designed plug and plays heart-rate sensor for Arduino. It also includes an open-source monitoring app that graphs your pulse in real time. The Pulse Sensor can be connected to arduino with jumper wires.

C. The GSM Module

Four frequencies GPRS/GSM Module is an ultra-compact and reliable wireless module. It is a breakout board and minimum system of SIM900 Quad-band GSM/GPRS module. It can communicate with controllers via AT commands (GSM 07.07, 07.05 and SIMCOM enhanced AT Commands). This module supports software power on and reset. The GPRS is configured and controlled via its UART using simple AT commands. Just connect on the Arduino board, you could easy to use AT command control it. This board can be connected to PC via FT233RL or USB-to-Serial Bridge Controller.

D. LCD Display Unit

LCD (Liquid Crystal Display) screen is an electronic display module and finds a wide range of applications. A 16x2 LCD display is a very basic module and is very commonly used in various devices and circuits. These modules are preferred over seven segments and other multi-segment LEDs. The reasons being: LCDs are economical; easily programmable; have no limitation of displaying special & even custom characters (unlike in seven segments), animations and so on. A 16x2 LCD means it can display 16 characters per line and there are 2 such lines. In this LCD each character is displayed in the 5x7 pixel matrix. This LCD has two registers, namely, Command and Data. The command register stores the command instructions given to the LCD. A command is an instruction given to LCD to do a predefined task like initializing it, clearing its screen, setting the cursor position, controlling display etc. The data register stores the data to be displayed on the LCD. The data is the ASCII value of the character to be displayed on the LCD. Click to learn more about the internal structure of an LCD.

E. Mobile User

The mobile user is simply any GSM mobile phone that is able to send and receive an SMS. The microcontroller issues control signal which instructs the GSM Module to send an SMS remotely over the GSM network to the GSM Mobile phone which receives the message sent to it. The GSM Module and the program algorithm can also be designed that the SMS message sent is to multiple predefined mobile users.

1.4 Working of the device

Monitoring heart rate is very important for athletes, patients as it determines the condition of the heart (just heart rate). There are many ways to measure heart rate and the most precise one is using an Electrocardiography. But the more easy way to monitor the heart rate is to use a Heartbeat Sensor.

It comes in different shapes and sizes and allows an instant way to measure the heartbeat. Heartbeat Sensors are available on Wrist Watches (Smart Watches), Smart Phones, chest straps, etc. The heartbeat is measured in beats per minute or bpm, which indicates the number of times the heart is contracting or expanding in a minute.

In this project, we have used Heartbeat sensor module to detect Heart Beat. This sensor module contains an IR pair which actually detects heartbeat from the blood. The Heart pumps the blood in the body which is called heartbeat when it happens the blood concentration in body changes. And we use this change to make a voltage or pulse electrically. When the first pulse comes, we start counter by using timer counter function in arduino that is millisecond function. Take first pulse counter value form millisecond function.

Then we wait for five pulses. After getting five pulses we again take counter value in time2 and then we subtract time1 from time2 to take original time taken by five pulses. Then divide this time by 5 times for getting single pulse time. Now we have time for the single pulse and we can easily find the pulse in one minute, dividing 600000 milliseconds by single pulse time.

Rate= 600000/single pulse time.

2. Proposed System

In this section, we would be describing the mathematical model, system architecture of the proposed system. Also, the algorithm used in the system would be briefly discussed.

2.1 Mathematical Model

Our system can be best described in mathematical terms, as there might be a certain amount of confusion at the initial modules of the system architecture.

Let 'S' be the system which processes the ECG signals, analyzing the features present in then, does the Cardio-Vascular disease detection and sends the alert to the doctor.

S = { s , e , X , Y , fkey , DD , NDD , Xprob | Øs , Success, Failure}

Where,

s : first state/ initial state
e : end state/ final state
X : set of input
Y : set of output
fkey : Functions that detect the Cardio-Vascular disease.
DD : Deterministic data
NDD : Non Deterministic data
Xprob | Øs : Type of problem
Success : state of achieving the desired goal.
Failure : state of failing to achieve the goal.

1) Initial state (S):

   Acquisition of ECG signals through ECG sensors and electrodes.

2) Final state (E):

$$e = e1 + e2 \quad (1)$$

   The final state e, mentioned in (1), is the combination of sub-states, e1 and e2. Here e1 is two the state in which the classification of the ECG signals takes place into either the 'Arrhythmia' class or the 'Normal' class. The e2 state is responsible for sending the immediate alert to the doctor and patient's relatives in the form of an SMS or alarm on their smartphones.

3) Set of inputs (X):

   Input X can be given as,

$$X = \{Cnoisy, Id\} \quad (2)$$

$$Cnoisy = \{C1 \;^{v}\; C2\} \quad (3)$$

Our system works on the ECG signals. Hence the Cnoisy term in (2) indicates the ECG signals with noise (raw ECG signals). The term Id is the identification number of the patient whose ECG signals are extracted. The Cnoisy can come from two sources in our project, C1 or C2, where C1 are the noisy ECG signals of patients acquired from ECG sensors and C2 are the noisy ECG signals gained from the MIT-BIH database.

4) Set of outputs (Y):

Output Y is given as,

$$Y = \{\text{Heart-rate}, e1, e2\} \quad (4)$$

Here the Heart-rate gives the number of times the heart beats in a minute. Also the e1 and e2 correspond to the classification state and alert state respectively, mentioned in equation (1).

5) Key functions (fkey):

$$fkey = \{ f1\ (C1^{v}C2)\ ,\ f2\ (C1^{v}C2)\ \} \quad (5)$$

The fkey gives in (5) gives us the key functions that perform the decision making in the system. fkey is the combination of two functions, f1 ($C1^{v}C2$), which that removes noise from the ECG signals acquired from C1 or C2 (see (3)). Finally the f2 ($C1^{v}C2$) function finds whether the heart beats should be classified in the 'Arrhythmia' class or the 'Normal' class.

$$f1\ (C1^{v}C2) = \alpha 1 + \alpha 2 + \Delta + Sq + \beta \quad (6)$$

The noise removal function includes α1 which is low pass filter noise reduction, α2 which is high pass filter noise reduction, Δ which is differentiator based noise reduction, Sq is the squaring element and β gives us the sliding window integration.

$$[\text{freq, Time-period, R-R, THR}] \in f2\ (C1^{v}C2) \quad (7)$$

The output of the f1 ($C1^{v}C2$), after performing sliding window integration (β), is the frequency (freq) of the ECG signal. The time-period can be calculated by taking the inverse of this frequency. We term this time-period as the R-R interval. The threshold THR can be calculated as,

6) Deterministic data (DD):

The data received as the output from the intermmediate states is called deterministic data. This data can be easily known to us and has no ambiguity.

$$DD = \{Cnoisy, Id, Val1\} \quad (8)$$

The values of Cnoisy, and Id can be referred from (2). Val1 is the output of the function f1 ($C1^{v}C2$).

7) Non-deterministic data (NDD):

The output of some states cannot be determined. For example, in our system, the end state may classify the beat into 'Arrhythmia' class or 'Normal' class. This classification is unpredictable. Hence we call it as non-deterministic data.

$$NDD = \{Val2, e1, e2\} \quad (9)$$

Here Val2 is the result of f2 ($C1^{v}C2$) while e1 and e2 can be referred from (1).

8) Problem type (Xprob | Øs):

A problem can be solved in polynomial time (P class) if the search version and the verification version of the problem are both easy to solve, however if the verification version of a problem is easier than the search version then we classify the problem into NP-complete class (solved in non-polynomial time). The search version of our system can be defined as: input the ECG signals that are purified from the preprocessing module. Find the signals that come into 'Arrhythmia' class, depending upon irregular beat pattern. The verification version can be defined as: input some random ECG signal and find whether it comes in 'Arrhythmia' class. Here the verification version is simpler than the search version. Hence the problem type (Øs) of our system is NP-complete.

9) Success:

There can be two successful outcomes of our system, first, when the correct classification of the signal takes place and second, when the alert is sent to the doctor at the right time in case of emergencies.

10) Failure:

The failure conditions should be considered while the construction of our system takes place. The two major failure outcomes can be, first, when the classification of the ECG signal goes wrong and hence, second, when a false alert is sent to the doctor.

2.2 System Architecture

There are total 5 modules in the system. These modules constitute the acquisition (shown by module 1) of the ECG signals, their processing (shown by module 2 and 3), alerting (module 4) functionalities of the system and the application of music therapy (module 5).

It is important to note that the system takes input from the MIT-BIH database as well as through device used by the patient.

The system architecture of IoT-BEAT is shown in fig 3.

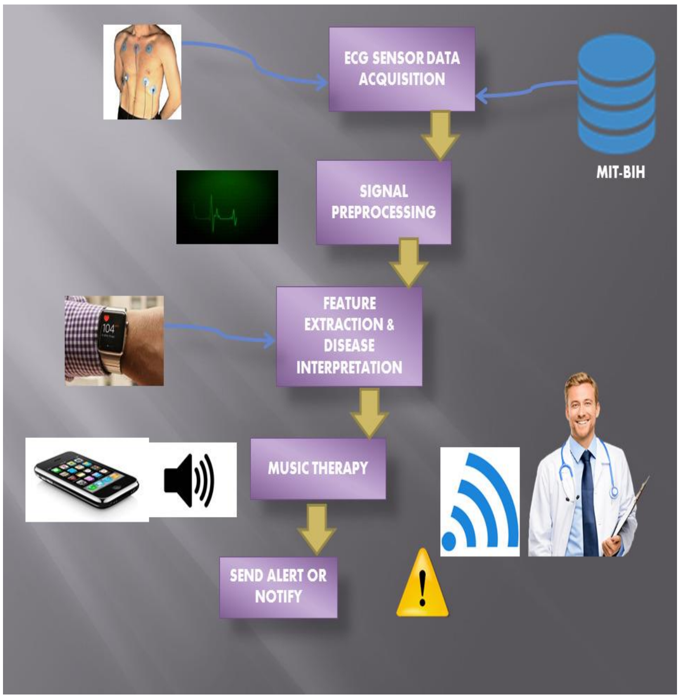

Fig -3: System Architecture

A. Module 1: ECG sensor data acquisition

This module acts as the starting input acquirer where the ECG signals are acquired either from the human body (through the device) or from MIT-BIH database. The MIT-BIH database is one of the large online repository consisting of 30 minutes of ECG signals of 48 patients.

The device we are developing will consist of pulse sensor which is used to get ECG signal from the human body at the real time. These signals contain noise and are called as raw ECG signals. Working with such signals may generate a lot of errors hence we need to remove noise from them. For this purpose, these signals are fetched to the preprocessing unit for processing.

B. Module 2: Signal pre-processing

The input to the module is the raw ECG signal. The module removes the noise in the raw ECG signals by filtering them. Filtering involves many sub-components like a low-pass filter, high-pass filter, differentiator, squaring element and integrator. The pre-processing task is tough. The filtered signal is fetched to the feature extraction phase.

C. Module 3: Feature extraction and disease interpretation

The input to this phase is the noiseless ECG signal. This module extracts the R-R interval feature of the ECG wave. The irregular beats are found using this feature. If the ECG signal is found to be irregular, it is classified into Arrhythmia class, else into the Normal class. The output of this module is either of the above classes.

D. Module 4: Alert (SMS)

This module gets input as Arrhythmia class or Normal class. An immediate alert is sent to the doctors and the relatives in case of emergencies (Arrhythmia detection). The alert will be in the form of an app notification to the doctor. This would result in doctor taking quick actions to admit the patient.

E. Module 5: Music Therapy

Here, the music appropriate Indian classical musical raga will be played from smartphone of the patient

1) If the patient has a past record of 'Asthma' then music in raga **"Malhar"** will be played.
2) If the patient has a past record of 'Hypertension' then music in raga **"Todi"** will be played and if the patient has a past record of 'Low Blood pressure' then music in raga **"Malkauns"** will be played.
3) If the patient does not lie in the above-stated categories then the music in raga **"Yaman"** will be played for some duration of time(probably for 5-6 minutes). In case that the patient's stress does not get reduced (i.e. heart rate does not get reduced to the normal range), then music in raga **"Darbari Kanada"** will be played.

2.3 Algorithm

ECG is a psychological phenomenon and also has effects of physical environment. Hence the ECG signals vary from person to person. For this reason, we cannot use a single ECG signal pattern as an ideal one to compare the ECG signals of all the patients. We preferred Pan Tomkins algorithm.

A. Algorithm: Pan-Tomkins

```
Initial: ECG Signal
Procedure PAN_TOMPKINS(Noisy ECG)
Stage_1 = High_passFilter(Noisy ECG)
Stage_2 = Low_passFilter(Stage1)
Stage_3 = Differentiator(Stage_2)
Stage_4 = Stage_3 * Stage_3
Stage_5 = Integrate(Stage_4)
Plot Signal.PQRST(Stage_5);
Calculate Signal.RR_interval;
End Procedure
procedure DECISION MAKER(Extracted RR interval)
if Data > HardThreshold then
Decide the patient is abnormal;
```

```
Transmit the data;
Store the data samples in the local storage;
Else
Decide the patient is normal;
Transmit the data;
Store the data samples in the local storage;
end if
end procedure
```

This algorithm is also called as QRS detection algorithm. We are using this algorithm to calculate the heart rate.
Heart rate (in beats/second) can be calculated by the following formula:

$$Rate = 60 * sampling\_rate / (RR\_interval)$$

B. Algorithm: Adaptive Rule Engine

We are using adaptive rule engine to avoid fake alert sending. Using this adaptive rule engine algorithm we can easily and accurately predict the disease. This algorithm avoids the rapid SMS sending.

```
Initial: Set HardThreshold values
Set SoftThreshold = HardThreshold
Set abnormal count=0 and start timer T;
Procedure DECISIONMAKER(ExtractedFeatures)
Comment: Calculate PR, QRS, QT intervals.
Calculate Data.PR interval ;
Calculate Data.QRS interval ;
Calculate Data.QT interval ;
if T expires then
Reset SoftThreshold;
Restart timer T;
end if
Decide the data is abnormal;
if Data > HardThreshold then
Decide the data is abnormal;
Store the data in local storage;
if Data > SoftThreshold then
CONTROL SECTION(on);
Transmit the data;
if abnormal Data.PR interval then
SoftThreshold.PR interval=
Data.PR interval ;
else if abnormal Data.QRS interval then
SoftThreshold.QRS interval=
Data.QRS interval ;
else if abnormal Data.QTinterval then
SoftThreshold.QT interval=
Data.QT interval ;
end if
Set abnormal count=0;
else
Do not change SoftThreshold parameters;
abnormal count = abnormal count+1;
end if
else
Decide the patient is normal;
Do not transmit the data;
end if
end procedure
procedure CONTROLSECTION(ControlSignal)
if ControlSignal == on then
Switch on the transmitter;
Wait for the data to be transmitted;
Switch off the transmitter;
else
Maintain transmitter in off state;
end if
end procedure
```

2.4 Working of the system

Our system would monitor the ECG waves and would also analyze it to do the decision making regarding the occurrence of Arrhythmia. In the case where the waves are normal meaning the heart is functioning properly, our system would send a normal report to the doctor at regular intervals.

However, if an episode of Arrhythmia is detected, our system would instantly fetch an alert report to the doctor and to the relative. Also, at the same time, our system will apply the music therapy for the arrhythmia patient to calm down means to reduce heart rate up to normal level. The three basic cases we have considered for our system are as described below:-

1) If the heart rate is in the range of 85-95 (beats/min), then music will be played automatically from the smartphone of the patient.
2) If the heart rate is in the range of 95-105 (beats/min), then music will be played automatically from the smartphone of the patient as well as the notification will be sent to the doctor.
3) If the heart rate goes beyond 105 (beats/min), then the music will be played automatically from the smartphone and an alert (SMS) will be sent to doctor of a patient and close relatives (3 relatives).

3. FUTURE SCOPE

In this paper, we have described the system which calculates the heart rate of the cardiac patient using pulse sensor. The music therapy is applied depending upon the different ranges of heart rate. As mentioned in this paper, the music therapy is applied from the smartphone of the cardiac patient. In future, the heart rate will be calculated using the wearable devices as well as the music therapy will be applied from the wearable device. Similarly, the concept of the music therapy can be applied for other diseases like diabetes, sunstroke, etc.

4. CONCLUSIONS

The system with remote monitoring feature would be helpful for the hospitals that face insufficiency of infrastructure for admitting the patients. This feature would allow monitoring of the patient from their homes or anywhere, maintaining their comfort level. The heart checkups will be done by our system and not by the doctors. Thus reducing the money spent on paying the fees of doctors. This project can be used as an inexpensive alternative to Smart Watches and other expensive Heart Rate Monitors. Its instant alerting feature, in case of emergencies, would certainly prove to be a boon for the present cardiac caring techniques.

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