An IoT based Low-Cost ECG Monitoring System for Remote Patient

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***Abstract*—In this era Internet of Things (IoT) had been proven a lot more helpful and smart in various applications and still continues to be useful. The most promising application of IoT is in the field of health care sector. In some countries, people still do not have access to quality health facilities owing to different barriers. The physical distance between patient and clinic is one of the foremost reasons. This paper studies the application of IoT in health care domain and a system is proposed to monitor the ECG of the distant patient. This system comprises of Raspberry Pi, Arduino Uno, ECG Sensor and IoT Cloud for storing and plotting ECG data in real time.**

***Index Terms*—Internet of Things, Raspberry Pi Model 2, Arduino Uno, IoT Cloud, ECG, healthcare, MQTT**

I. INTRODUCTION

Now a day's an Internet of Things (IoT) is to be considered as a dynamic global network infrastructure where objects with unique identities are interconnected for enabling advanced services. It is the next paradigm shift where sensors and actuators are connected with each other and exchange the data without human intervention. Nowadays the penetration of internet across each the corner of the globe has really opened the new spectrum of solutions to almost every problem which is being faced by society. Health monitoring of a patient distantly has become an easy and plausible task with the advent of this technology.

The cardiovascular abnormality is one of the biggest causes of deaths among people of all races around the globe especially in the case of old age people. In few years, it is expected that the world population of age 65 and older would exceed the population of the world with age of 15 years. Moreover, Economic advantages would come through reduced physician and emergency room visits, reduction in the hospitalization and nursing care at individual homes. Thus, to check the real-time functioning of the heart, distant patient ECG (Electrocardiogram) monitoring systems are designed by different researchers and designers in literature. Indoor ECG monitoring system has been developed by some designers to use this system for non-technical users.

II. MOTIVATION

Traditionally, the ECG is detected through large and stationary equipment in professional medical institutions. The kind of equipment usually employs twelve electrodes to collect ECG data due to their good performance in short-term measuring. However, the equipment is unlikely to be portable, which means that patients' activities are severely limited during the period of data collection. Moreover, as these devices are usually too expensive for home use, patients have to go to hospital frequently, which will inevitably increase the burden for them. Since it has become possible to utilize the advancements of Computation and Internet of Things in the domain of health care to support senior citizens at homes, athletes, and people from all walks of life. So with the development of this system the elder patients will have the facility to get them diagnosed from the comfort of their home without traveling to hospitals.

III. RELATED WORK

In literature, several systems for same have been proposed but they met few limitations. Indoor ECG monitoring system has been developed by some researchers to use this system for non-technical users but the main drawback of this system was its range of operation which was limited by the Bluetooth technology which has the range of around 10 meters.

P. Singh and A. Jasuja, [1] *"IoT based low-cost distant patient ECG monitoring system."* They have studied the application of IoT in health care domain in which a system is proposed to monitor the ECG of the distant patient. In the proposed system the Bio signals are collected from the Body of the patient using ECG sensor and sent to distant cloud IBM Bluemix, for further analysis by a physician or other authorized person. In this literature the components used proved to be low cost.

M.R.F.Nurdin, S. Hadiyoso and A. Rizal, [2] *"A low-cost Internet of Things (IoT) System for Multi-patient ECG's monitoring.*" The authors had discussed one application of IOT as media data transmission for the ECG signal. They have designed the system that can be accessed by several users simultaneously via the internet network. The system consists of ECG hardware, Zigbee for transmission module and web server for storage. There are few issues and this system could only handle 20 users due to insufficient bandwidth and high data traffic on server.

Lin, Alice M, Wong and Kevin C, et al, [3] "*Community-Based ECG Monitoring System for Patients with Cardiovascular Diseases"* The authors have developed a community-based electrocardiogram (ECG) monitoring system for cardiac outpatients to detect heart rate to provide personalized health care of patients. In the proposed system the signals of patient were recorded with help of dry electrode. The cost of system is comparatively more than IoT based systems and there are few issues.

E. Spano, S. Di Pascoli, G. Iannaccone, [5] *"Low-Power Wearable ECG Monitoring System for Multiple-Patient Remote Monitoring,"* The authors developed low-power ECG monitoring system with a wearable facility. The focus of this development was to design a system with attributes viz. low cost, wear ability, and low energy per bit and they used ZigBee protocol was used for data transmission from a sensor. There was no Real time notification in this system.
Yang Z, Zhou Q, Lei L, et al., [6] *"An IoT-cloud Based Wearable ECG Monitoring System for Smart Healthcare."* The authors have studied and found out and implemented new method for ECG monitoring based on Internet-of-Things (IoT) techniques. The results reveal that the proposed system is reliable in collecting and displaying real-time ECG data, which can aid in the primary diagnosis of certain heart diseases.

Furthermore, some systems were proposed by the researchers based on web implementation but the costly hardware used by them made this system out of reach of those people who are financially not able to afford it. Android mobile phone based system is also developed which receives the bio medical sensor data from the dedicated processor and store the data to SD card installed on the mobile phone. But the main problem with this design was its incapability to visualize the data in real time. This paper discusses the system which sends real time ECG graph data to web based distant cloud using MQTT protocol.

IV. IMPLEMENTATION OF PROPOSED SYSTEM

The complete flow of information in proposed system is explained below. The block diagram of the proposed system is shown in figure. Components used in the system can be divided into 2 parts: Hardware components and software component. We will briefly give the information about each component of the system and subsequently the working of all components as a whole system. The architecture of the IoT-based ECG monitoring system is illustrated in following figure, which mainly consists of three parts, i.e., the ECG sensing network, IoT cloud, and GUI.
The components used in ECG Sensing network are: ECG AD8232 Sensor, Raspberry Pi Model 2, and Arduino Uno.

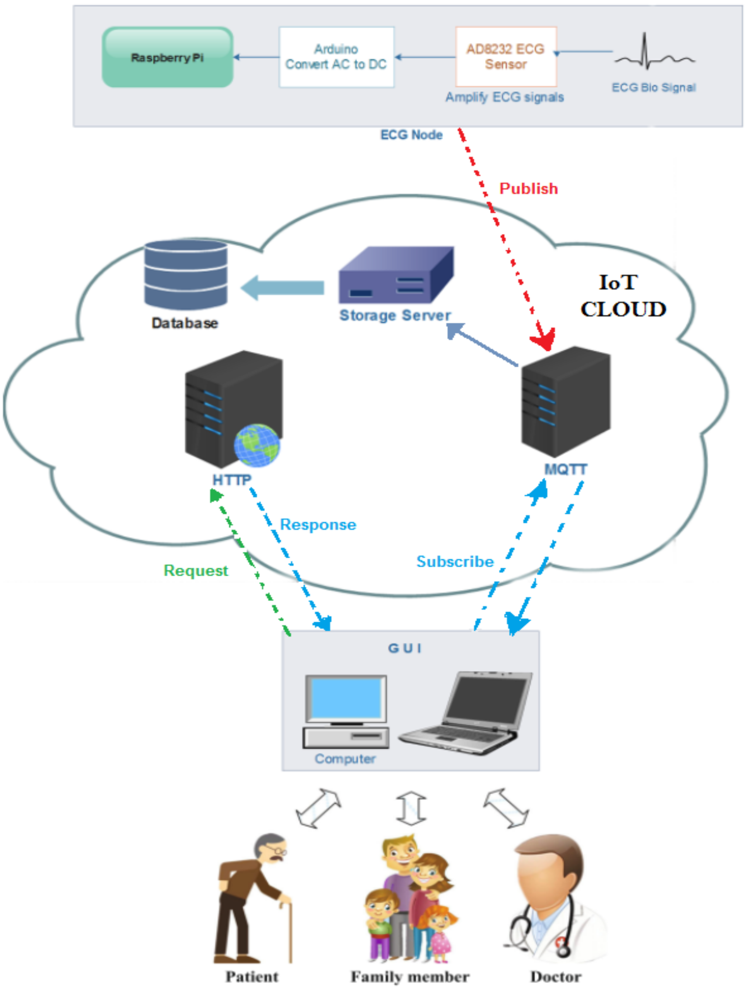

Fig 1: Implementation of the ECG Monitoring System

A] Hardware Components
This system contains the following hardware components.

1) Raspberry Pi
The Raspberry Pi Model 2is a small sized mini-computer of the second generation developed by Raspberry pi foundation in the UK. Though it is the cheap yet really effective and powerful tool for interfacing with many devices at the same time. Based on the latest ARMv7 32-bit processor it is powerful and faster than the previous models. Raspberry pi 2 model used in our system have the following technical specifications-

Features	Raspberry Pi 2
CPU	Broadcom BCM2836 32bit Quad Core
Clock	900 MHz (Can be Overclocked)
Ram	1GB SDRAM
GPIO	40 pin
USB Port	4x USB 2.0
Flash	None
Storage	micro SD
Network	10/100
Wi-Fi	Yes

2) Arduino Uno
Arduino is an open source microcontroller. The Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the micro controller on the board.
”Uno” means one in Italian and was chosen to mark the release of Arduino Software (IDE) 1.0. The Uno board and version 1.0 of Arduino Software (IDE) were the reference versions of Arduino, now evolved to newer releases. The Uno board is the first in a series of USB Arduino boards, and the reference model for the Arduino platform. Below are the technical specifications-

Microcontroller Features	ATmega328P
Operating Voltage	5 V
Input Voltage	7-12 V
Clock Speed	16 MHz
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
Flash Memory	32 KB (ATmega328)
SRAM	2 KB
EEPROM	1 KB (ATmega328)

3) AD8232 ECG Sensor
ECG stands for Electrocardiogram which sense the heart’s electrical pulse also called bio-signals which then helps to plot graph of heart rate. The AD8232 Single Lead Heart Rate Monitor is a cost-effective board used to measure the electrical activity of the heart. This electrical activity can be charted as an ECG or Electrocardiogram and outputs it as an analog reading. ECGs can be extremely noisy, the AD8232 Single Lead Heart Rate Monitor acts as an op amp to help obtain a clear signal from the PR and QT Intervals easily.
The AD8232 is an integrated signal conditioning block for ECG and other bio potential measurement applications. It is designed to extract, amplify, and filter small bio potential signals in the presence of noisy conditions, such as those created by motion or remote electrode placement.

Below is the AD8232 ECG Wired Sensor.

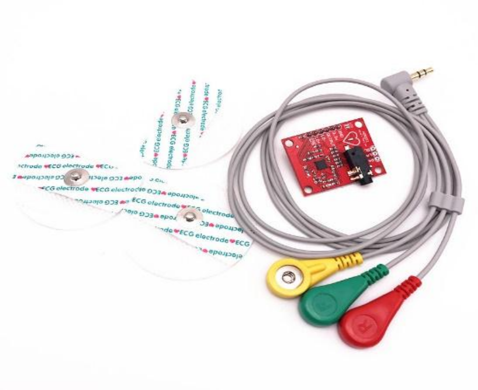

Fig 2: AD8232 ECG Sensor

B) Software Components

Linux-based operating system named Raspbian OS is installed on the device Raspberry Pi using micro-SD and in Arduino, application code is written in Arduino programming language. The application code is written in IDE (Integrated Development Environment) of Arduino. IDE contains the text editor to write the application code according to requirement. The codes written in IDE are also known as sketches and .ino file extension is used to save these sketches. After compiling, the codes are uploaded to Arduino board.

Graphical User Interface to Monitor ECG

Instead of having additional mobile applications, users can log in to the IoT cloud and acquire ECG data directly by just visiting a certain website using a web browser of any OS platform. Therefore, nearly all smart terminals, including desktop PCs, laptops, and smart-phones, are able to obtain the service of the IoT cloud.

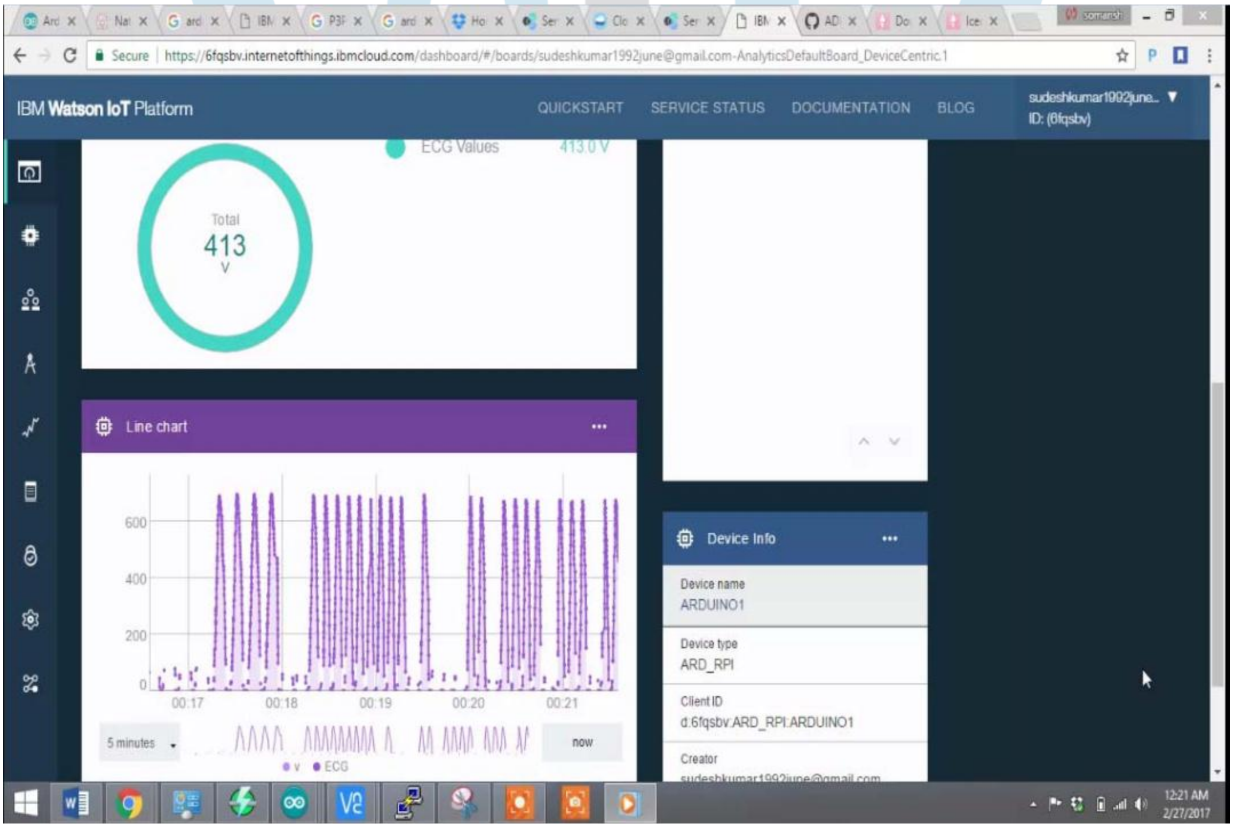

Fig 3: Snapshot of GUI of IBM Bluemix with plotted ECG graph.

Apart from displaying real-time ECG signal, users can also obtain the historical data by selecting the start time and end time in the control panel.

Mathematical Equations

This 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.

$$S = \{ s, e, X, Y, fkey, DD, NDD, X\text{-}prob \mid Øs , Success, Failure \}$$

Where, s : first state / initial stat
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
X-prob | Øs: Type of problem
Success: state of achieving the desired goal
Failure: state of failing to achieve the goal

Algorithm

The ECG signals can vary from one person to another. For this reason, one cannot use a single ECG signal pattern as an ideal one to compare the ECG signals of all the patients and hence, we preferred Pan Tomkins algorithm.

Algorithm: Pan-Tomkins
0: Initial: ECG Signal
1: **Procedure** PAN TOMKINS(Noisy ECG)
2: Stage 1 = High passFilter(Noisy ECG)
3: Stage 2 = Low passFilter(Stage 1)
4: Stage 3 = Differentiator(Stage 2)
5: Stage 4 = Stage 3 * Stage 3
6: Stage 5 = Integrate(Stage 4)
7: Plot Signal.PQRST(Stage 5);
8: Calculate Signal.RR interval;
9: **End Procedure**
10: procedure DECISION MAKER(Extracted RR interval)
11: if Data < HardThreshold then
12: Decide the patient is abnormal;
13: Transmit the data;
14: Store the data samples in the local storage;
15: **Else**
16: Decide the patient is normal;
17: Transmit the data;
18: Store the data samples in the local storage;
19: **end if**
20: **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:

$$Rate = 60 * sampling\ rate / (RR\ interval)$$

V. EXPERIMENTAL EVALUATION

The system can be divided into 4 parts, namely The Sensors, The Processing Unit, The Cloud and Real Time Notification.

Sensor Node

In this system, monitoring heart is very important for athletes, patients as it determines the condition of the heart rates. 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. 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 sub part, the ECG bio-signals are taken from patient's body by using the gum based electrodes attached to patient's body. The ECG signals are extremely noisy as these signals may get affected by muscles activities and by the movement of subject's body. After acquiring the signals the signals are fed to AD8232 block which remove the noise and amplify the signals before passing them to next stage.

Signal Processing Unit

In this unit, the signals coming from the previous stage are given to Arduino. As raspberry pi is a general purpose minicomputer so it does not contain inbuilt ADC (Analog to Digital Convertor).The Arduino is used to converts the Analog signals to digital which makes this system less vulnerable to noise as the use of dedicated ADC would have increased the wiring which would lead to further contamination of the acquired bio signals.
By using the Serial-In node of Node-Red, which is installed on Raspberry Pi, the data (coming from the sensor) is sent to Raspberry from Arduino. Moreover for internet connectivity, Wi-Fi Modem is attached to the Raspberry Pi and subsequently, data is deployed to IBM Bluemix cloud as the Raspberry Pi is registered to the Bluemix cloud.

NODE-RED: Node Red is an open source visual editor that allows programmers of any level to rapidly interconnect physical I/O, cloud based systems, databases and most API's in any combination you can imagine. This is an incredible flexible and powerful tool.

Bluemix IoT Cloud

The signals are transmitted from Raspberry Pi to IoT cloud by Wi-Fi module attached to the Raspberry Pi. For the secrecy of the data, identification process has been ensured so that only authorized person would have the access to patient's data. The data collected by the sensor from the patient body can be plotted in real time on the distant cloud to be visualized by the authorized physician.

MQTT Server

The HTTP server only provides a graphical interface to the ECG signal. However, the transmission of ECG data from the monitoring node to the web page is implemented based on the Message Queuing Telemetry Transport (MQTT) protocol. It is a publish/subscribe protocol in contrast to HTTP which uses request/ response architecture. The main difference between the HTTP and MQTT is that in the case of MQTT, broker pushes the information to the client while in HTTP the client makes the request to get the information.

MQTT works on following concepts

- Publish and Subscribe: In this system, your device can publish a message for other devices or your device can subscribe to a particular topic to receive those messages.
- Massages: Messages are information which are exchanged between your devices whether it can be command or data.
- Topics: Topics are the way you register interest for the incoming messages that you want to subscribe. Topics are represented with strings separated by slashes"/". The slashes indicate the topic level.
- Broker: Broker is basically responsible for receiving all incoming messages, filtering the messages, decides who's interested in it and then publishing the messages to all the subscribed clients.

Real-time Notification

The notification service is a real-time notification to inform about abnormal situations under these conditions.
- If the heart rate is in the range of 85-95 (beats/min) or the QRS time interval is less than or equal to 0.1 sec. and the QRS voltage is in the range of 0.5-0.7mV.
- Secondly, if the heart rate is in the range of 95-105 (beats/min) or the QRS interval is greater than 0.1 sec and voltage is less than 0.4mV.
- Finally, If the heart rate goes beyond 105 (beats/min) or the heart rate is not in the range of normal heart rate which is defined by American Heart Association.

Notification messages are categorized into three groups having level 1, 2 and 3 respectively. Depending on particular situations, the push notification generates different messages with corresponding levels.

Result and Analysis

The following figure plots part of the ECG data collected from the healthy volunteer. It is evident that the intervals between

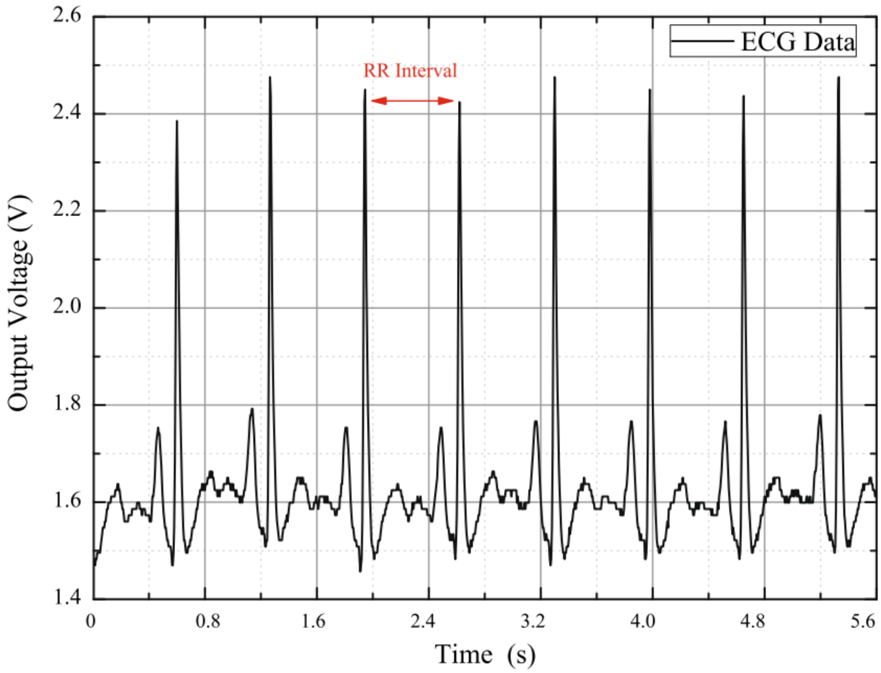

Fig 4: Real time ECG Signal

adjacent R waves (RR interval) are nearly the same, which shows no risk of developing arrhythmia.
Typical ECG consists of following things,

RR interval: As one of the most conspicuous characteristics, the R wave is often used to identify the period of an ECG signal. RR interval indicates the time interval between two adjacent R waves, which may become irregular in the event of some heart diseases, for example, the arrhythmia.
PR interval: The PR interval measures the time between the beginning of the P wave and that of the QRS complex. It indicates the time the impulse takes to reach the ventricles from the sinus node.
QT interval: QT interval represents the time between the start of the Q wave and the end of the T wave, which is related to the ventricular depolarization and repolarization. There is an increased risk of ventricular fibrillation or even sudden cardiac death if the QT interval exceeds the normal value.

VI. CONCLUSION

From this system it is seen that, the ECG monitoring system that is based on IoT is low cost and efficient for remote patient. The architecture of the ECG monitoring system was presented at first. The components of the system are Raspberry Pi, Arduino and ECG AD8232 Wired Sensor were introduced and compared. With the help of an ECG AD8232 monitoring sensor node with three electrodes, real-time ECG signals can be collected with satisfactory accuracy. The gathered data were transmitted to the Bluemix IoT cloud using Wi-Fi from Raspberry Pi. The IoT cloud is responsible for visualizing the ECG data to users and storing these valuable
Data for further analysis, which is implemented on the basis of the HTTP server, MQTT server, and storage server. Eliminating the need for mobile applications, the web-based GUI provides a versatile means independent of any mobile OS platform for users to access the ECG data. This system is low-cost compared to other existing systems in literature and can also provide Real Time Notification when the ECG signals of patient are abnormal.

VII. FUTURE-SCOPE

Similar to this user-friendly ECG monitoring System, additional health monitoring real time systems such as Blood Pressure, Diabetes, etc., can be developed that will greatly help decrease existing health care problems to a certain amount.

VIII. ACKNOWLEDGMENT

Apart from my own success, I am very much thankful to my guide Prof. S V. Athawale for his expert guidance and continuous encouragement throughout to see that this seminar meets the target since its commencement to its completion.

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