An IoT Based Remote HRV Monitoring System for Hypertensive Patients

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***Abstract*—Heart Rate Variability (HRV) is a measure of variation in the time interval between consecutive heart beats. HRV analysis is highly sensitive for risks linked with Cardiovascular disease, Diabetic Mellitus, disease states associated with Autonomic Dysrhythmia such as Hypertension and a large array of chronic degenerative medical condition. Sensitivity of HRV towards various medical condition accounts for its increased usage by doctors as a diagnostic, prognostic tool and to evaluate the effectiveness of the treatment offered. Often borderline hypertensive patients with and without history of a cardiac event are subjected to stroke as well as cardiac mortality at high risk. Monitoring of HRV parameters for such cases of high risk will prove useful in providing adequate medical care at needed times. In this paper, the authors propose a low-cost and easy to use Remote HRV Monitoring System based on the Internet of Things (IoT) technology for borderline Hypertensive patients. In the proposed system, HRV parameters are derived using Wireless Zigbee based pulse sensor. Arduino transmits patient data to server using MQTT protocol. The application server collects HRV data and plots graphs. In case of an emergency situation, the care taker and doctor are intimated through Short Message Service (SMS) for providing adequate medical help. While there are currently no HRV analysis systems that alerts at times of high risk for hypertensive patients along with the aid of a remote doctor, the proposed system aims at achieving the same. The proposed system combines the dual benefits of Zigbee and WiFi technology. By doing so, it successfully fulfils all the ideal traits of a remote health monitoring system in terms of low-cost, long range, security, promptness and easy-to-use that serves in saving lives.**

Keywords—Heart Rate Variability (HRV); Hypertension; Cardiovascular disease; Diabetic mellitus; Internet of Things (IoT); Zigbee; Transport Level Security (TLS); Message Queuing Telemetry Transport (MQTT).

I. Introduction

Our era have been seeing plethora of chronic and critical health problems. With the rapidly growing need for timely medical services, the traditional method of treatment at the clinic or hospital more often falls short in accomplishing success with respect to emergency cases. A method to sense life threatening risks prior to the actual happening sounds to be the need of the hour. IoT for healthcare offers to be a vital solution in adjourning such a serious issue. IoT, the inter-networking of various real world objects has become a popular phenomenon. With the rise in advent of sensors and actuators for use with various platforms, healthcare industry is being revolutionized by breaking the traditional methods.

Of many chronic illnesses, Hypertension has become common yet a serious disease that remains as the root cause for major Cardiac mortality and Stroke mortality.

Hypertension is a condition where the blood pressure in the arteries of the body is higher than 120/80 mm Hg (more than 120 systolic and more than 80 diastolic). Though it is often a condition occurring in the elderly, children are also susceptible to fall prey to it. Hypertensive heart disease has topped the table for its death toll in India according to Global Burden of Disease Study 2013 [16]. Critical health events like Stroke or Myocardial Infarction (Heart attack) related to Hypertension does not happen all of a sudden, rather it is a continued risk factor that results in such life threatening events. HRV is as an important parameter that uncovers even dilate intricacies regarding health condition. The study of HRV enhances our understanding of physiological phenomenon, the actions of medications and disease mechanisms [8]. HRV parameters acts to be a predictor for Cardiovascular disease risk [7]. Thus, the proposed system aims to remote monitor as well as alert in critical situation based on the HRV parameters and Heart rate for borderline Hypertensive patients.

The proposed system that is based on IoT shares the results of sensor data in terms of graph and manipulated HRV data to a remote medical practitioner through a web application. This helps in following up the patient's condition without a hospital visit and to check the effectiveness of the treatment offered by the doctor. Currently, there are several standards and proprietary devices that support sensor networks [9]. Of all comparable standards, IEEE 802.11 WiFi and IEEE 802.15.4 Zigbee are believed to be reliable standards. To capitalize the potential of such a dynamic system that is proposed here, the Quality of Service (QoS) and Security in wireless transmission of data needs to be taken care of. This is satisfied by the proposed system with the usage of a light-weight publish/subscribe messaging protocol MQTT for IoT. Publish/subscribe messaging paradigm is found much useful in remote monitoring systems. In a publish/subscribe paradigm, the messages are published to an intermediate messaging broker and the subscriber shall obtain the required message from the broker by subscribing. A topic-based publish/subscribe system (sub-categorical in publish/subscribe system) where the publisher publishes the messages to a topic (named logical channel) and the subscribers receive messages from a topic to which they are subscribed is used in the proposed system. MQTT for their well-known levels of QoS solves the QoS problem that was to be addressed. In terms of security, TLS, a cryptographic protocol ensures secured transfer of data from remote patient to a Server at the doctor end alongside MQTT.

There are currently no remote HRV analysis systems for hypertensive patients available to help doctors track the progression of the patient's condition and serve as an alert system prior to critical medical events. Though several other remote health monitoring systems have been built in literature,

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our proposed system aims to be more reliable, low-cost, low-power, long-range and easy-to-use for patients combating with the deadly Hypertension in everyday life.

The paper is organized as follows: Section II explains about related work. Section III describes the detailed architecture of the proposed system. Section IV briefs about implementation and results with reference to the proposed system model. Section V concludes the paper with its future scope.

II. Related Work

Internet of Things (IoT) technology based Remote patient monitoring using web services and cloud computing has been built in [1]. The system uses an IOIO microcontroller board that obtains ECG signals and sends it to the mobile device wirelessly using Bluetooth technology. An android application had been used to collect, store and transfer the ECG data further. The application also visualizes the data collected at the front-end. The collected data was saved as a binary file. The patient at the mobile device end was connected to the File Transfer Protocol server (FTP) via Filezilla to upload the files. The server also supports multiple user logins with authentication. At the other end, the medical professional can download all the uploaded data of the patient from the FTP server for analysis of the patient's ECG waves. The highly unstructured binary files uploaded through a FTP server is stored in a filetable. The filetable manages the files and the file metadata in a synchronized manner. The system incorporates a higher level of communication like machine to machine communication.

Remote monitoring system of ECG and Temperature signals was implemented using Bluetooth technology in [2]. It uses an Arduino Uno board with ATmega328 microcontroller as data acquisition unit and for Analog/Digital conversion. ECG acquisition takes place on a 3-lead module followed by filtering and amplification of acquired signals. The INA 128P integrated circuit was used for its recommended usage in the medical devices. Data was transferred to a local device (Personal computer or Mobile phone) through Bluetooth technology. Captured and visualized signals are then sent to a remote database for storage which could be accessed by a web application deployed on server. A wireless 3-channel ECG transmission system that caters to monitor the health of the old using a Personal Digital Assistant (PDA) phone had been developed in [3]. The system consists of two ATmega328L microcontrollers, one with Zigbee transmitter and another with Zigbee receiver. The transmitter end collects data, stores in a Secure Digital (SD) card and transmits. The receiver sends collected data to a remote server. It aims to cope with sudden attacks of diseases by continuous monitoring. A vital sign monitor based on wireless sensor networks and Telemedicine has been executed to measure the vital parameters like ECG, Heart rate and Respiration rate in [12]. It uses Bluetooth technology with sensor to transmit data to a smart phone. An application had been designed and used in the smart phone to transfer data to a remote server through WiFi/3G for centralized monitoring. On the remote server end, a LabVIEW based application shall do the necessary analysis on the obtained patient data especially heart rate over the entire long period of monitoring. A specialist application shall also provide a window based look into the patient's condition from the obtained data. A remote physiological parameters monitoring system has been designed and developed in [4]. The system comprises of heart rate sensor and temperature sensor to be worn by an at-risk person that is connected to a computer wirelessly. The device monitors as long as the data is logged into the system and sets up an alarm through the connected computer in the home when the parameters are found to be in risk level.

MQTT has been presented as the most widely applicable lightweight, fast communication, efficient protocol for IoT in [10]. MQTT is found to reduce network traffic and minimizing transport overhead for dynamic communication in IoT according to the survey. MQTT is completely found suitable for usage with constrained devices indulged in sensor networks. HRV had been monitored for hypertensive patients in the Indian population and is proved that HRV parameters are significantly reduced for hypertensive patients compared to normal, healthy subjects in [13]. Similarly, most time domain features of HRV have been proved to be much lower for hypertensive patients as compared to normal subjects in [5]. The research involved 57 hypertensive patient and 57 normal subject to use HRV parameters for diagnosis of hypertension in [5]. An analysis of 30 normotensive and 30 hypertensive subjects have been done in [6]. The analysis concluded that the hypertensive condition could be well monitored and managed with the help of HRV time domain parameters which are drastically lowered compared to normotensive person.

HRV has been proven to be a vital parameter for monitoring of Hypertension disease. IoT in healthcare connected to a remote database or a remote server would serve for promptness in times of emergency, earlier diagnosis and prevention. Acknowledging the usefulness of IoT for borderline hypertensive patients, the proposed system in this paper is a design of low-cost, secured, scalable and efficient Remote HRV monitoring system which has been our motivation.

III. Architecture of Proposed Model

The Fig. 1 gives an overview of the proposed system architecture. The working and background of each component in Fig. 1 is as detailed below.

A. *Wireless Pulse Sensor Module*

This is the sensor module that is to be attached to the patient body that acquires patient's pulse data (heart beat data) (shown as 1.(a) and 1.(b) in Fig. 1).

1) *Wireless Pulse sensor:* The Pulse sensor (shown as 1.(a) in Fig. 1) used detects the heart beat by the method of a Photoplethysmograph (PPG). PPG illuminates the skin optically and measures the pulse as a variation of resistance to the blood flow in the skin. The sensor could be attached to the finger/earlobe. The variation is obtained as a fluctuation in the

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analog values from the pulse sensor. As the heart pulse is detected, heart rate and Inter Beat Interval (IBI) are calculated alongside.

2) Zigbee Protocol: The use of Zigbee protocol (shown as 1.(b) in Fig. 1) in various health monitoring systems has become one of the most promising standards for short range wireless communication. While a lot of devices are incorporated with Zigbee standard, XBee is a 20-pin microcontroller made by digi that uses Zigbee protocol [14]. Operating voltage requirement of 3.3V accounts for the low-power consumption. There are three different roles that XBee could be assigned to in a network.

(i) Coordinator – must in every network as it takes care of the whole network. A network can have only one Coordinator.

(ii) Router – It deals with relaying data to the destination. Multiple routers may exist in a network.

(iii) End Point – These cannot relay signals, can only receive them. Multiple end points may exist in network.

XBees could be set to any one of two modes, AT or API mode depending upon its use. The XBee that senses data should be set to AT mode and the one receiving shall be set to API mode. In our system, two XBees would be used.

One (1.b in Fig. 1) acting as a router is to be connected to the pulse sensor module and be placed on the patient's body. This will be set to AT mode. The second XBee would be (shown as 2.(a) in Fig. 1) connected to the Arduino Platform. This XBee will be the coordinator in the network that is working in the API mode to receive data from the pulse sensor module XBee router.

B. Intermediate Gateway Unit

This module is responsible for establishing a secured communicating channel for transmission of pulse data from pulse sensor module to the severs (2.(a) and 2.(b) in Fig. 1).

1) Arduino Uno: The Arduino Uno is a microcontroller board that is embedded with ATmega328 microcontroller. The board is widely used as a platform with sensor and associated networks for their 14 Digital pins and 6 Analog pins on them. In our system, Arduino Uno board (shown as 2.(a) in Fig. 1) enabled with Zigbee through XBee and WiFi through ESP8266 (WiFi chip) is made to act as a gateway to the MQTT server from the Wireless Pulse sensor module. On the receiving end of the Arduino, XBee (placed in 2.(a) in fig. 1) set to act as coordinator shall receive data from pulse sensor module. Analog/Digital conversion is performed on the Arduino board. The data is formatted into JavaScript Object Notation (JSON) and is ready for transfer to the MQTT server. JSON's light-

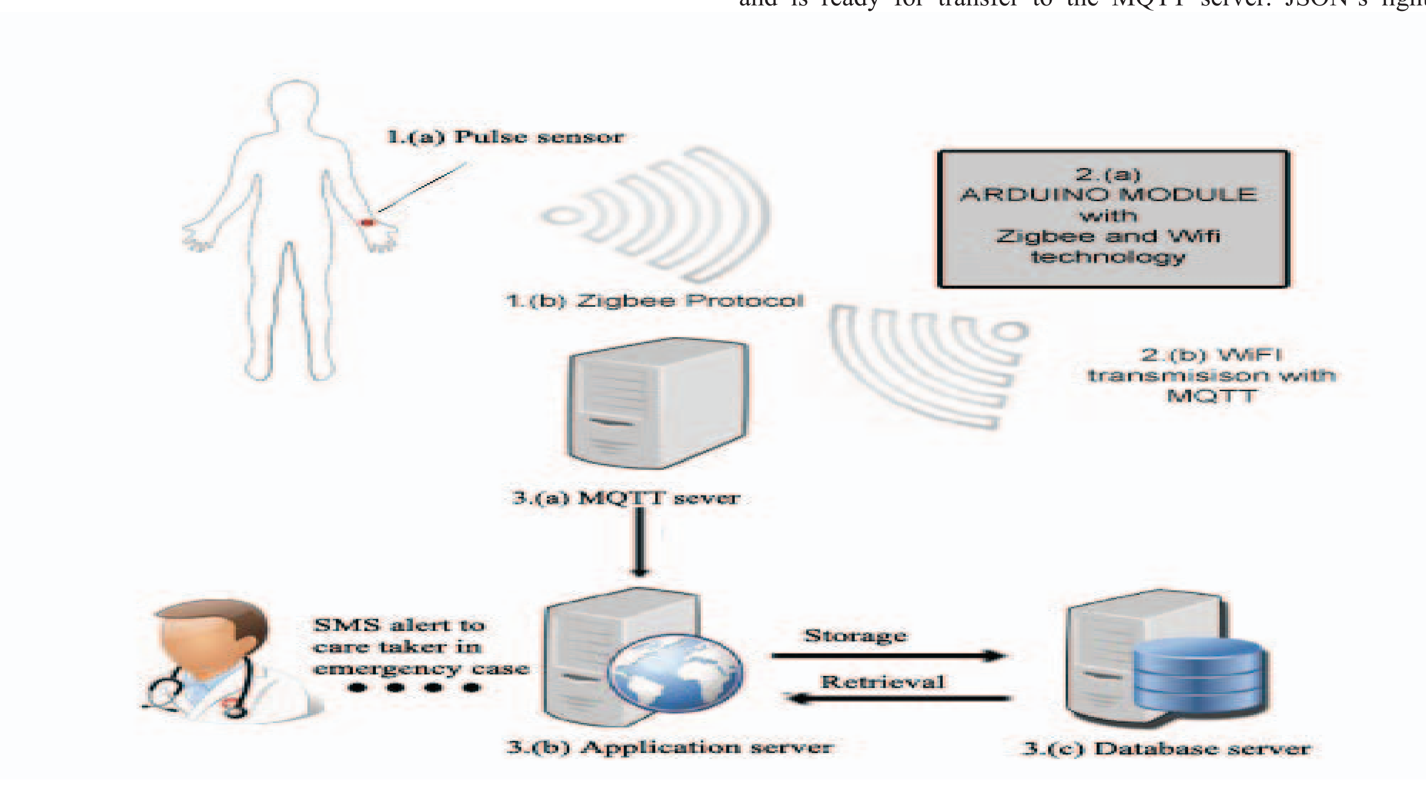

Fig. 1. Architecture of proposed system

weighted nature and faster communication makes it highly suitable for data interchange scenario compared to XML format.

2) WiFi transmission with MQTT : WiFi is the technology that connects devices to the internet via a wireless LAN network. It has long range communication compared to other wireless technology in the IoT networks. WiFi enabled Arduino in the proposed system shall transfer the JSON formatted data to the MQTT server utilizing MQTT as the messaging protocol (shown as 2.(b) in Fig. 1). Of various emerging protocols for connectivity of electronic, computing device and machine-2-machine (M2M) communication such as AMQP (Server to Server), XMPP (Machine to Human) and DDS (Machine to Machine), MQTT is designed specifically for collecting device data and communicating it to servers. MQTT v3.1.1 has now become an accepted standard for communication by Organization for the Advancement of Structured Information Standards (OASIS). QoS 1 (highest QoS for MQTT- “atmost once”) is used to properly make the data to reach the other end with acknowledgment messages between the sender and the receiver end.

MQTT depends upon Transport Control Protocol (TCP) as transfer protocol where security is traded off. For secured channel of communication, we use TLS protocol with MQTT in the proposed system [15]. TLS is a cryptographic protocol that is based upon a handshake mechanism comprising of data encryption with cipher texts meant for the MQTT server used. The certificate provided by the server is validated at client side. TLS protocol also specifies the type of certificates that must be exchanged for enhanced secured connectivity. The proposed system connects to port 8883 that is allocated for a secured MQTT connectivity.

C. Server End

The server end consists of three severs, MQTT server, Application server and Database server. The functionalities of the servers are as explained below.

1) MQTT Server: The MQTT server is the important part of MQTT communication. The sever acts as the intermediate messaging broker. In proposed system, a HIVEMQ 3.1.5 MQTT server is used to which the Arduino publishes the pulse sensor data to a topic “/pulse” and the web application subscribes to that topic “/pulse”. The data sent to the topic resides in the broker until any client subscribes and no data packet is lost.

2) Application Server: Websphere Application server (version 16.0.0.3) hosts the web application deployed. The JAVA web application subscribes to the “/pulse” topic at the MQTT server and stores all the incoming data in MYSQL Database that is connected with it. The incoming data is then used to trace the human pulse wave and to plot the R-R (beat –to-beat) interval histogram which clearly depicts the abnormal variation at first sight about the functioning of heart. The plots (pulse and R-R histogram) are rendered with the usage of Google charts Application Protocol Interface. The vital HRV time domain parameters namely, Standard Deviation of all Normal to Normal (SDNN) beat, NN50 - the number of pairs of successive NN (R-R) intervals that differ by more than 50 milliseconds and pNN50, the proportion of the NN intervals divided by the total number of NN (R-R) interval are derived and displayed alongside the histogram. Monitoring the mentioned parameters is taken care by the application. Based on the reference value ranges that has been observed in different age groups and gender by a study for nine decades in [11], the HRV parameters are monitored and the doctor’s laid down cut off points for a particular patient are applied as well. Authenticated log in is enabled for doctors and patients to access the application.

3) Database Server: MySQL 5.5 Database server is connected to the application end. The application queries the database every 5 seconds for plotting the histogram on incoming data and the last 30 seconds of the current/recent pulse logged into the system is displayed as the pulse wave. Each patient shall have their data stored in tables under their patient ID. The database makes viewing the historic data of the patient easily accessible.

IV. Implementation and Results

As first step into the execution of functionalities, the system was tested to act upon 3 normotensive and 3 Hypertensive patients aged between 30 and 60 by connecting the patient with pulse senor for 5 minutes. The following Fig. 2 shows the plotted pulse for a normal person and Fig. 3 shows the pulse trace of a hypertensive patient.

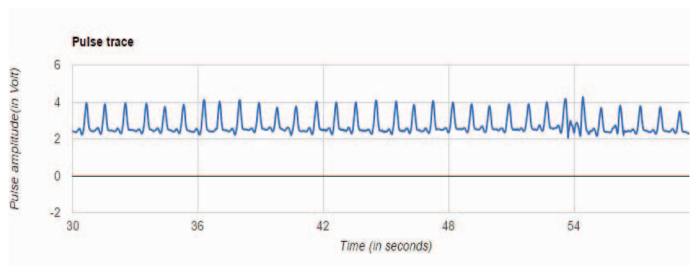

Fig. 2. Pulse trace for normal person

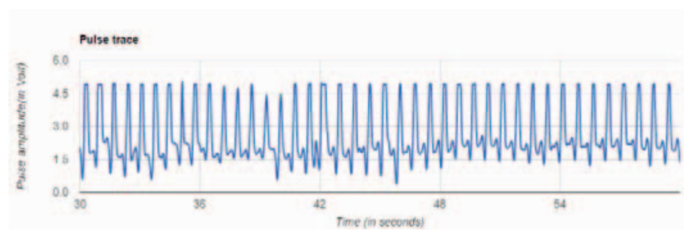

Fig. 3. Pulse trace for hypertensive patient

Fig. 2 is in accordance with the normal person’s pulse plot. The Fig. 3 graph shows much variation from that of a normal person’s denoting the inconsistent functioning of the heart and the increased beats per minute due to blood pressure above normal range. Thus, the line graph of the pulse provides first insight into the patient’s condition for the doctor. The HRV time domain parameters are displayed alongside the RR interval Histogram. HRV time domain parameter's normal ranges differ by the age group and gender of the subject under view according to a study in [11]. Since age plays dominant role in variation of HRV parameters than gender, the patient's age alone is taken into account here in this paper for analysing their medical condition (as gender normalises after 30 years of age and the subjects under view in this paper are aged above 30). Derived results of normal ranges for HRV time domain parameters as in [11] are used for analysis of patient's condition here in this paper. The heart rate and RR interval normal ranges does not differ by age and gender. Fig. 4 is the RR interval histogram of a normotensive person and Fig. 5 is the RR interval histogram of hypertensive patient.

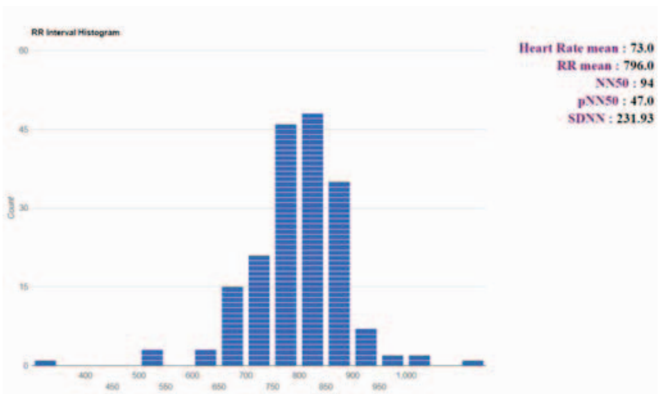

Fig. 4. RR Interval Histogram for normotensive person

For normotensive person the Heart rate is well within the normal range of 60-100 beats per minute at rest. RR interval mean (796.0 ms in Fig. 4) also lies in the normal limits of 600-1200 ms. pNN50 (47.0% in Fig. 4) and SDNN (231.93 ms in Fig. 4) time domain measures also reside within the normal range mentioned of [11] as 2-68 and 86-237 ms respectively for the normotensive person under view.

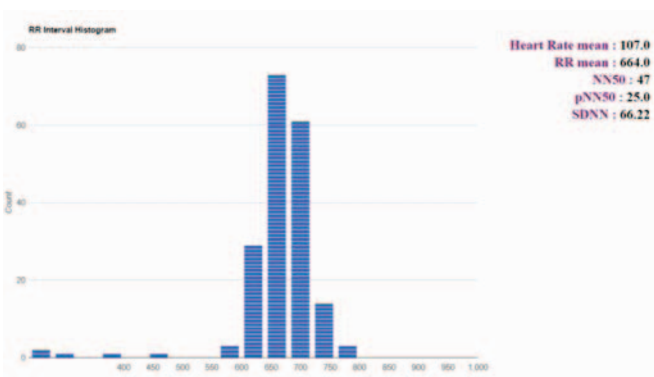

Fig. 5. RR Interval Histogram for Hypertensive patient

The normal person's histogram is also widely spread across the normal range of 600-1200 ms acknowledging that the beats are not rapid and there is sufficient time interval between each heartbeat proving normal functioning of the heart.

The RR interval histogram of hypertensive patient is highly narrowed down to 600-750 ms compared to the widely spread one with the normotensive person. This suggests that there is no sufficient time interval between successive heartbeats acknowledging that there are rapid heartbeats with the hypertensive patient under view. The Heart rate is well elevated for hypertensive patient 107.0 beats/minute where the normal range is 60-100 beats per minute. Though RR interval mean (664.0 ms in Figure 5) is just within the normal range of 600-1200 ms, it can be noted that it is reduced compared to the normotensive person. pNN50% normal range as in [11] for the hypertensive person under view is 1-48 and the observed value for the hypertensive patient is 25.0, though it lies within normal limits is reduced much compared to normotensive person. SDNN normal range according to [11] is 79-219 ms, whereas the observed SDNN for hypertensive patient is 66.22 ms which is much beneath the normal range denoting deviation from the normal functioning of heart due to high blood pressure. Table I gives the average results of measured values for 3 normotensive and 3 hypertensive patients.

TABLE I. MEASURED RESULTS

Measured Parameters	**Person under view**	
	Normotensive	***Hypertensive***
Heart Rate (beats/minute)	77.5	127.0
RR mean (ms)	789.0	579.5
NN50	97.0	61.0
pNN50%	43.5	27.5
SDNN	210.68	166.08

[a] $P < 0.05$ for all HRV parameters of normotensive and hypertensive patients for respective age

It can clearly be noticed that the HRV parameters are reduced much for hypertensive patients than normotensive from the respective normal ranges based on age and Heart rate of hypertensive patient is elevated above normal range, which acts as an indicator of increased risk for cardiovascular mortality and stroke mortality in hypertensive patients. These observed HRV parameters for hypertensive patients deviating from the normal range prove the impaired functioning of the heart due to existing high blood pressure within the vessels of the heart and body. When these parameters reach the laid down risk range as in case of onset of a severe condition asymptotically or left unnoticed, the care taker and doctor will be alerted through a SMS. The rendered graphs by the application could serve as the baseline with which the doctors monitor the patient and check the direction of patient's response to the treatment currently offered.

V. CONCLUSION

IoT has been breaking down various traditional computing methods in all arena especially healthcare. Concept of remote monitoring the patient's condition is one among the various break-through in healthcare industry by IoT. Various issues regarding power consumption, security in the wireless networks and efficiency in data interchange has proven to limit the usage of remote monitoring systems at large scale. The proposed system here has catered to solve all limitations and is designed to be more reliable, low-cost, easy-to-use system for Hypertensive patients by combining the benefits of Zigbee and WiFi technologies. Hypertension has become a serious threat to cardiac mortality and stroke mortality. HRV monitoring for borderline hypertensive patients will prove useful to provide adequate care to serious scenarios such as cardiac mortality and stroke mortality. There are currently no remote HRV monitoring system with aid of a remote doctor for tracking patient's condition and alerting at times of emergency for Hypertension patients. The proposed system achieves the same. The proposed system monitors the HRV parameters for Hypertensive patients through a web application. The application monitors the HRV parameters and provides results as graph. In emergency case, the system sends SMS to care taker and doctor to provide immediate medical help. The system was made to act on 3 normotensive and 3 hypertensive patients. The observation conclude that there is decrease in HRV time domain parameters beneath the normal range for hypertensive patients compared to normotensive person and much deviation from normal seen in rendered graphs of hypertensive patient indicating the increased risk for cardiac mortality and stroke mortality. Thus, the proposed system successfully function to monitor and provide insights regarding Hypertension condition. As a look into the future enhancements on the system, the web application could also be hosted on a cloud environment with storage and MQTT broker implemented with the same cloud environment.

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