IoT-Enabled Wireless Body Area Network (WBAN) for Real-Time Remote Health Monitoring

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Abstract:

The increasing adoption of Wireless Body Area Networks (WBANs) has revolutionized healthcare by enabling real-time remote health monitoring. The advancement of wireless sensor networks (WSNs) has been instrumental in developing WBAN-based Internet of Things (IoT) architectures, facilitating seamless communication between wearable medical devices and healthcare systems. This study presents the design and implementation of a WBAN system that integrates multiple devices and networks to efficiently transmit vital and non-vital patient health data to healthcare professionals. The proposed system enhances patient monitoring, ensuring continuous health tracking, timely interventions, and improved medical outcomes. By leveraging IoT-driven connectivity, this research highlights the potential of WBAN technology in advancing telemedicine, personalized healthcare, and emergency response systems.

Keywords: Real-Time Patient Monitoring, Telemedicine, Wearable Medical Devices, Healthcare Data Transmission, Biomedical Sensors, Smart Healthcare Systems.

Intoduction

Due to latest innovations in wireless technology and electronics, which offer intelligent and smart sensors that can be used on, about, in, or injected in the human body, pervasive health coverage is an evolving technique that guarantees rises in the reliability, precision, and accessibility of medical diagnosis. Wireless Body Area Networks (WBANs) are an active subject of study and research in this context, as they have the potential to greatly improve clinical care and monitoring.WBANs are made up of a variety of biological detectors. These detectors can be worn or inserted under the user's skin and are put in various regions of the body. Each one has its own set of prerequisites and is utilised for a separate set of tasks. These gadgets are used to detect feelings or human states like fear, anxiety, and joy, as well as to measure changes in a patient's vital indicators. They connect via a special fusion center, which uses less energy and has higher computing power.It is in charge of transmitting the patient's biological signals to the medical doctor in order to deliver real-time medical diagnostics and enable him to make the best decisions possible. Intra-BAN interactions, Inter-BAN connectivity, and beyond-BAN connectivity are the three layers of interaction in the WBAN basic design. Intra-BAN communications refer to communication between wireless body sensors and the WBAN's master node. Inter-BAN communications occur between the main server and personal gadgets like as laptops, home intelligent machines, and other similar devices.

The beyond-BAN tier establishes a connection between the personal device and the Internet. Several protocols, like Bluetooth and IEEE 802.15.4, enable interaction between separate sections. IEEE 802.15.6 was created specifically for WBAN applications and meets the bulk of their needs. However, it appears to be less performant in several circumstances when compared to other WBAN-supporting technologies. Because each technology has distinct qualities that allow it to meet the limits of some apps 4, Wi-Fi, Bluetooth, and cellular services can all be used to develop WBAN applications. WBAN applications, in reality, cover a wide range of topics in order to enhance the users' quality of life.These applications are classified mostly by whether they are employed in the medical or non-medical fields. Medical applications mostly consist of healthcare solutions for the elderly and unwell.

Early diagnosis, treatment, and tracking of diseases, geriatric care at home, post-surgery rehabilitation, biofeedback programmes that control emotional states, and assisted living apps that enhance the quality of life for persons with impairments are just a few examples. Body sensors utilised in health monitoring3 can be one of two types: (a) neurobiological detectors that assess human body bio - signals internal or external, such as body temp, blood pressure, or ECG; or (b) biokinetic sensors that accumulate human organism movement-based signals, such as velocity or angular rate of rotation.Ambient sensors can be paired with body sensors to provide extra data about air temperatures, environment stress, illumination, or humidity. Indeed, because these sensors are responsible for regulating the setting, they might provide vital extra data for diagnosis and therapy, which is common in the home setting 8. However, while designing WBAN applications, several technical considerations should be taken into account, like node motions and temperatures, node placements, and limited node capacity in terms of energy and computation. Other limits closely linked with wireless technology, like the short area range, data rate, etc, must be considered while communicating between onbody and in-body nodes.

2. Design and Implementation

In this section we discuss about the various components/equipment used in building our WBAN.

Spo2Sensor

Spo2 is used for measuring oxygen levels in the body. It is calculated by measuring the amount ofoxygen carrying hemoglobin to the amount of hemoglobin not carrying oxygen. An oxygen levelbetween 96 and 100 is considered normal. It is usually placed on the index finger and gives thepulsereading.

HbO_2 = oxygenated hemoglobin Hb = deoxygenated hemoglobinPulse Sensor

A pulse sensor is used to accurately measure the heartbeat of a person. It calculates the beats perminute of a person. An optical heart rate sensor measures pulse waves which are changes in thevolume of a blood vessel that occurs when the heart pumps blood. Measuring the change in volume using an optical sensor and a green LED are used to detect pulse waves. It has three pins Vcc, Gnd,andadatapin.

DHT11Sensor

Itisusedtomeasurebothtemperatureandhumidity.DHT11sensorisusedtodetectthetemperature of the person in WBAN. It has an inbuilt thermistor to detect the temperature of the person. It works on a 5vsupplyandhasthreepinsnamelyVCC,Gnd,and a data pin.

Microcontroller

An ATmega328P is used for collecting the data from pulse, Spo2, and DHT11 sensors. The sensorsare connected to the microcontroller using wires. An Arduino IDE software is used for dumping codeintothemicrocontroller.Thedatacollected issent to theend deviceZigBeemodule.

NodeMCU ESP8266ESP-12E:

The ESP-12E module on the NodeMCU ESP8266 control board has an ESP8266 chip with a TensilicaXtensa 32-bit LX106 RISC CPU. This microcontroller supports RTOS and has a clock frequency band of 80MHz to 160MHz. NodeMCU has 128 KB of RAM and 4MB of Flash memory to store programs and data. NodeMCU may be powered by the micro USB jack and the VIN pin (External Supply Pin). It has UART, SPI, and I2C connections. Its high processing power, built-in Wi-Fi / Bluetooth, and Deep Sleep Operating characteristics make it ideal for IoT applications.In our IoT system, NodeMCU is connected to the coordinatormodule of Zigbee and this microprocessor is responsible for the uploading of values recorded fromthe patientontotheInternet.

XBEES2CProTransceiverModule

This is a 63mW 3Km Zigbee XBee Pro S2C 802.15.4 Module. The ZigBee RF modules XBee and XBee-PRO allow low-cost wireless communication to electronic products. They work with other ZigBee PRO feature set devices, including those from other manufacturers. The XBee 802.15.4 devices make setting up dependable end-point communication a breeze. The input supply voltage for the Zigbee S2C pro is 2.7-3.6V. The data rate of this module is 250kbps, and its outdoor distance is rated at 3200 metres. This chip's transceiver chipset module is the Silicon Labs EM 357 SoC. This module supports Mesh Network topology.

3.SystemDesignZigbee

The System designed has a Zigbee end device and Zigbee coordinator module. The Zigbee enddevice is connected to ATmega328P (Arduino) module. The coordinator module is connected toNodeMCU module. The Zigbees were configured as end device and coordinator using DIGI XCTUSoftware. Theimplementation doneis of a single enddevicebutthe system deployedhas aprovision were up to a maximum Number of 65000 (Theoretical Number) nodes (end devices) canbe connected to our System's Network , the network operating is configured in a self healing meshtopology.Allthreesensorssendtheirdatatothemicrocontroller.Themicrocontrollerafterreceiving the data values sends the data to the transmitter ZigBee module. The transmitter Zigbeemodule transmits the data to the coordinator Zigbee module through a wireless medium which inturn sends the data to the web server via NodeMCU. The coordinator ZigBee transmits the data toNodeMCU.The No-deMCU reads valuesusingthe followingcode

```
while(XBee.available())

{


intx=XBee.read();

)
```

WhereXBee.available() states to get in the loop when there is data available XBee.read() states toread data in the NodeMCU. The web server values are then sent over to a custom website thatregularly updates its values based on the data coming in from the sensors. The web application canbe used for remote monitoring of the patientirrespective of where the person lives. It can beaccessed by the doctors, administrators and the patientby signingin with the appropriate ID.Doctorscanmonitorthe healthofthe patientbyreadingthe graphfromthe webapplication.

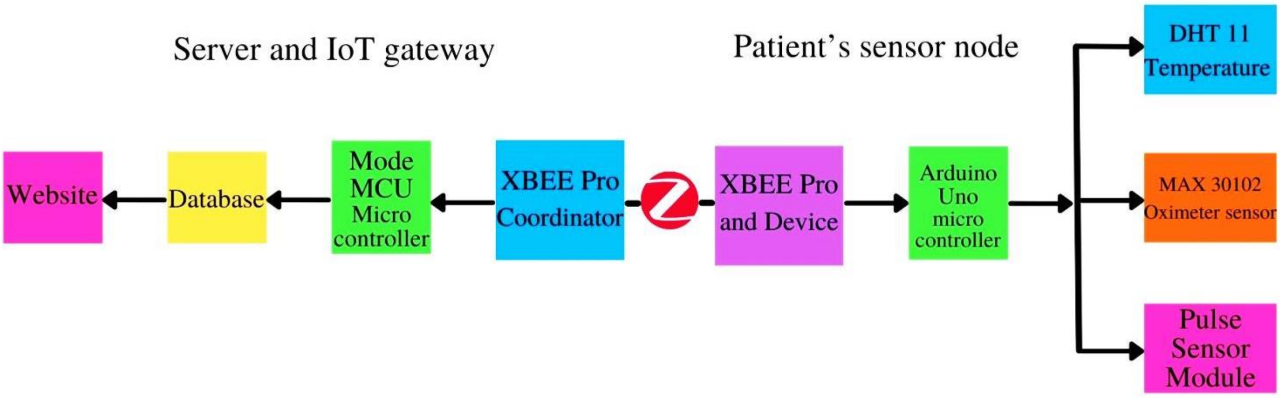

Fig1:WirelessCommunicationUsingZigbee

Zigbee operates on the IEEE 802.15. 4 system and was developed for low-power, low data rate IoTdevices. Zigbee is flexible as it supports all types of routing such as mesh, ring, star, tree, etc. It canconnect to about 65000 nodes. It has a transmission capability up to a distance of 100 meters. EveryZigBee has a router, coordinator, end device. Coordinator is responsible for address handling,forming the network, and letting the network function. A router is a node in a large network. It canaccess, receive and transfer data to and from another node. They act as messengers in a network.End devices are the final nodes in the net- work. They do not act as messengers (routers) and areusually low-cost, low- power devices used for the transmission and reception of data. Zigbee has alow data rate of 250 Kbits/sec and a frequency band of 2.4 GHz. Because of low bandwidth, theZigBee saves battery by sleeping most of the time. It uses Direct Sequence Spread Spectrum whichcontributes tosavingpower.TwoZigbeemoduleswereusedinourSystem,onefortheenddevice and the otherforthecoordinator.

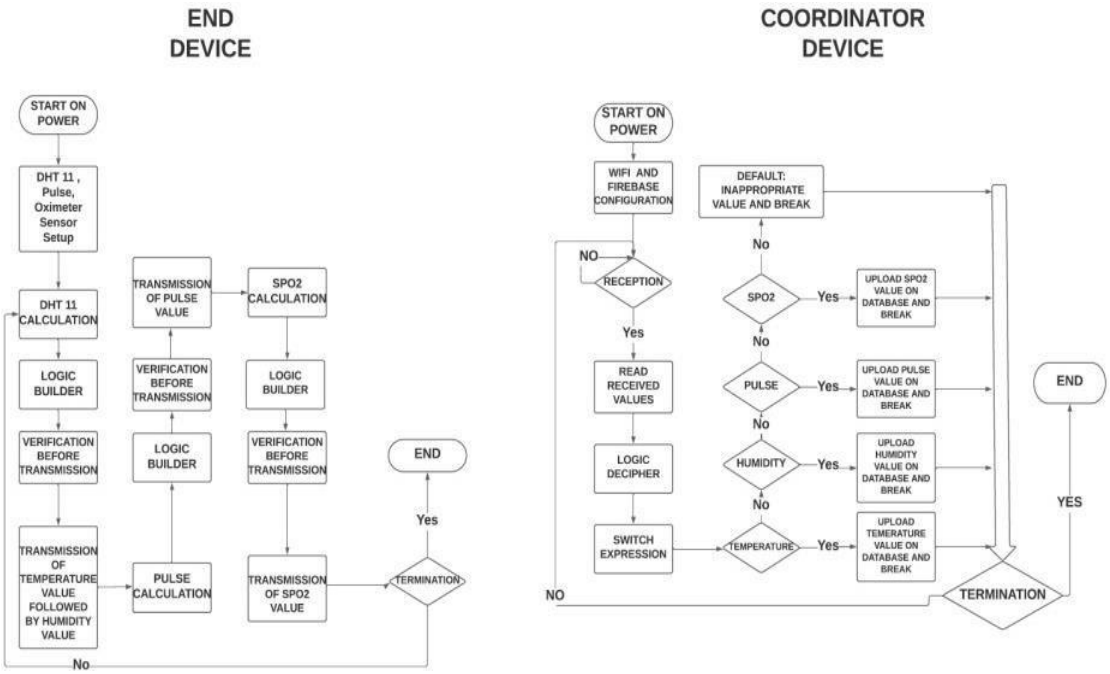

Fig 2: Zigbee End device and coordinator deviceTable 1:ComparisonofIEEE802.11,BluetoothandZigbee

	IEEE802.11	BLUETOOTH	ZIGBEE
AtteryLife (Days)	4	1-7	100
Nodes per network	30	7	65000
Range(meters)	1-100	1-10	1-75
Topology	Tree	Tree	All
Frequency	2.4GHz	2.4GHz	2.4GHz
Memory	100kb	100kb	60kb

Routing

With the usage of nodes, Zigbee Standard mainly has three topologies, star topology, tree topology,andthemeshtopologyalsonamedaspeertopeertopology.Thestartopologyhasahighdependence on the coordinator, any packet exchange between end devices must go through thecoordinator. The coordinator becomes bottlenecked because of the excessive flow packets into it.Star topology does not provide any alternative paths for the communication between source anddestination.

The tree topology has its central node as coordinator and there are router and end devices present inthisnetwork[7].Routers helpinextendingnetworkcoverage andthe enddevices are eitherconnected to the router or coordinator. In tree topology if the parent node becomes disabled then thechildren cannot directly communicate with each other even if they are geographically close to eachother [10]. There is a special case of tree topology named cluster tree topology but this topology isnot supported by Zigbee (but IEEE 802.15.4 supports it). Mesh topology proved to be the bestfitfor our system for several reasons, including the fact that it is a multi-hop network comprised ofcoordinators, routers, and end devices. The network's range can be expanded by adding moredevices tothenetwork;themaximumlimitis65000devices,allowingustohavealargeandrobust

networkforourIoTsystem.Thistopology removesdeadzones.DuringTransmission,Meshtopology's nodes can find an alternative path to the destination, if a path fails. Because of thisalternative path adaption feature our data transmission will never get abruptly terminated and ourIoT system cannot compromise with a certain amount of data not getting transmitted. In simplewords, we cannot afford to lose a patient's health status for any given amount of time and we areimplementing a continuously monitored health system. The power consumption can be reduced bydecreasing the proximity between the devices, through means of this we can (ask) provide a systemthat has decreased battery consumption at the end devices nodes and in the entire network. Anysource deviceinthenetworkcancommunicatewithanydestinationdevice.

Security

Zigbee provides some of the most secure IoT wireless devices. The protection of values transmittedor received is of utmost importance to us and our IoT system cannot withstand any tampering ofthese values. The patient is examined based on these values; hence we need to have a Robust andSecure IoT System. Zigbee's security is based on symmetric-key cryptography, which requires twopartiestointeractusingthesamekeys.

Zigbee includes a 128-bit extremely secure encryption scheme based on AES [8]. Cryptographicsecurity occurs solely between devices in Zigbee. cryptographic protection is not present betweendifferent layers in a device as Zigbee operates on an 'open trust' architecture,in which the protocolstack layers trust one another. All the devices on a given network and all the layers of a device havethe samelevelofsecuritytoprovide simpleinteroperabilitybetweendevices.

Zigbee works on a principle "thelayer that originates a frameis responsiblefor initially securingit".To stop replay attacks ZigBee commandincludes aframe counter, the receiving endpointalways checks the frame counter and ignores duplicate messages. Zigbee is immune to jammingattacksasitsupportsfrequencyagilitywhereinthenetworkisrelocated/reallocated.

A Centralized security model which provides higher security was implemented, thismodelincludes atrustcenterwhichis a

network coordinator and in our IoT system it is the Xbee S2C pro module connected to node MCU.The trust center is responsible for the authentication of routers and devices which are going to jointhe network. As devices join the network, the TC generates a unique TC Link Key for each one, aswell as link keys for each pair of devices as needed. The network key is likewise determined by theTC.Withthismodel'simplementation,a vigorousimpenetrableIoTsystemwascreated.

XBeeZBVSnrf24L01

Fortheinstallationofawirelesscommunicationstandardinour IoTsystem,wethoroughlyreviewed all wireless communication standards and compared Xbee (Zigbee) to all current wirelessstandards,withZigbeeindisputablywinning.TheonlymodulethatcameclosetoZigbee'scomparison is a radio module named nrf24l01. To dispel common misunderstandings about nrfsimplementationanditserroneouslyperceivedbenefitsover ZigBee,thefollowingfactsarestated.

1. The nrf module must be used in connection with a microcontroller; other- wise, it will use morespace,resultinginaheftyproduct.Zigbeecan functionwithout theuseofamicrocontroller.

2. The Zigbee standard runs on three frequencies: 2.4 GHz, 868 MHz, and 915 MHz, whereas nrfrunsonasingle2.4GHzISMband.

3. The nrf module is powered by an Arduino at 3.3 volts. Due to the inadequate current provided bythe Arduino board, which is less than 50ma, the nrf module shows sporadic and ridiculousactivities.

4. When using the RF24 nrf24l01 library, even a 2000mAh battery will last just 5 days, but theXBee wouldlastforyears[9].

5. The nrf transceiver does notgive any way for measuring received signal strength values, whichisasignificantdisadvantage.

6. While its operation in mesh networking the nrf module was not able to get into sleep mode atall.TheRF24libraryhastobeimprovedtosupportsleepcyclesandamechanismwasneededtofinddynamicimplementationofsleepmode.

Firebase

Firebasehasbeen usedasdatabaseinthiswork.All thevaluesaregettinguploadedby thecoordinator NodeMCU into this database. Firebase is a real-time database and this allows us tocontinuously read and write values into the data base. As it is a continuous monitoring system thatoperates in real-time, Firebase is the best fit. Firebase is a Google platform and it was integratedwith the proposed system using the Firebase open source Library <FirebaseArduino.h> built byGoogle. The firebase is simply connected by providing the Firebase URL and database secrets' key(Authentication key)in our Arduino IDE code. The integration of Webappis done by embeddingthe firebase Javascript SDK in the web app. The website can now easily read data from this real-time database, the data read is visualized on the website. Firebase is highly protected and the userhascustomizablesecurityoptions.

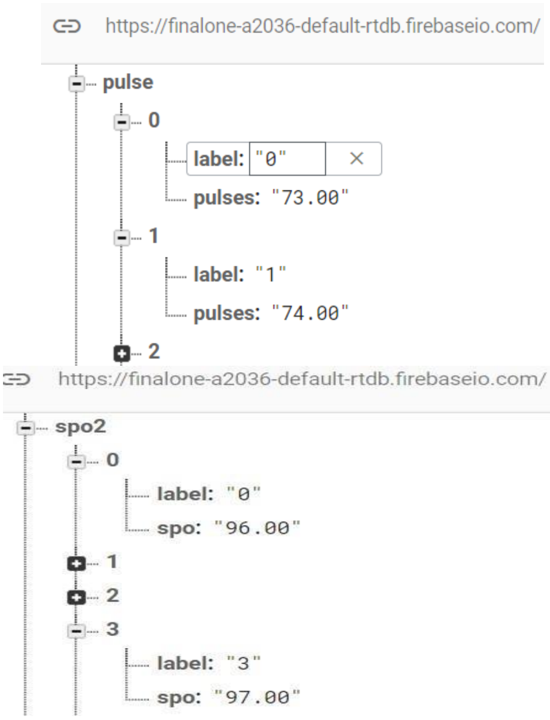

Figure 3:Screenshotofcaptureddata

Website

The Web application provides an intuitive user interface where users can view real-time healthmetrics plotted in a graphical format. To access the aforementioned plots the user needs to clear anauthorization level wherein the user's credentials are verified, upon successful clearance the user isredirected to the login page. The platform offers bio-medical values of patients, hence, enablingcontinuoushealthmonitoring.

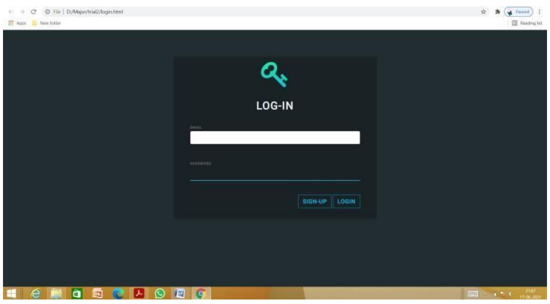

Fig4: Loginpage

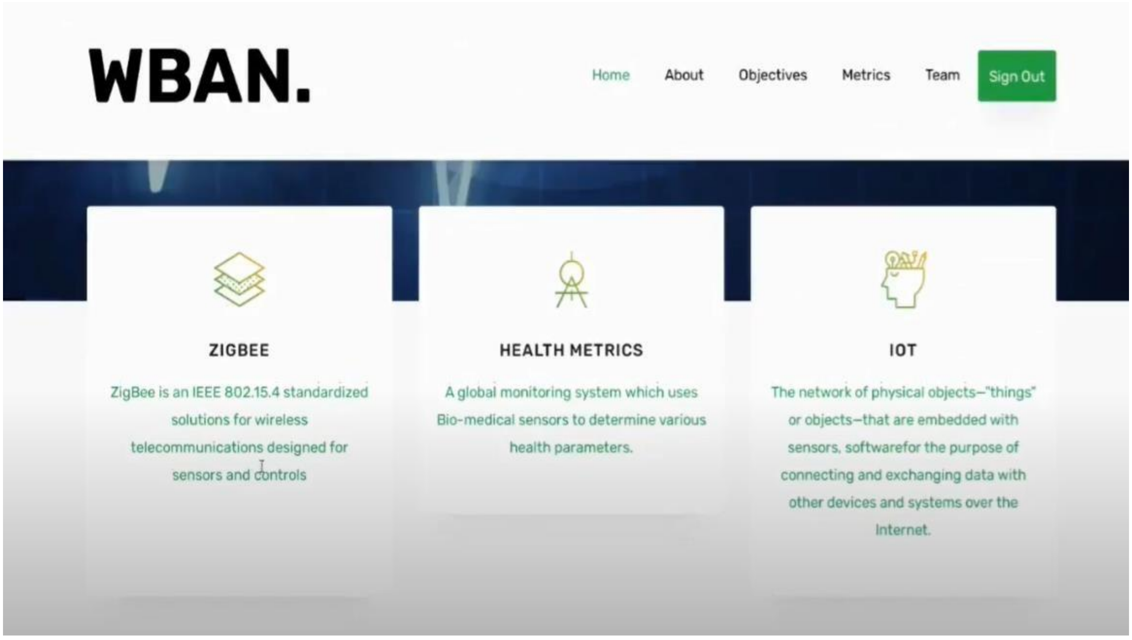

Fig5:WebsiteIntroduction

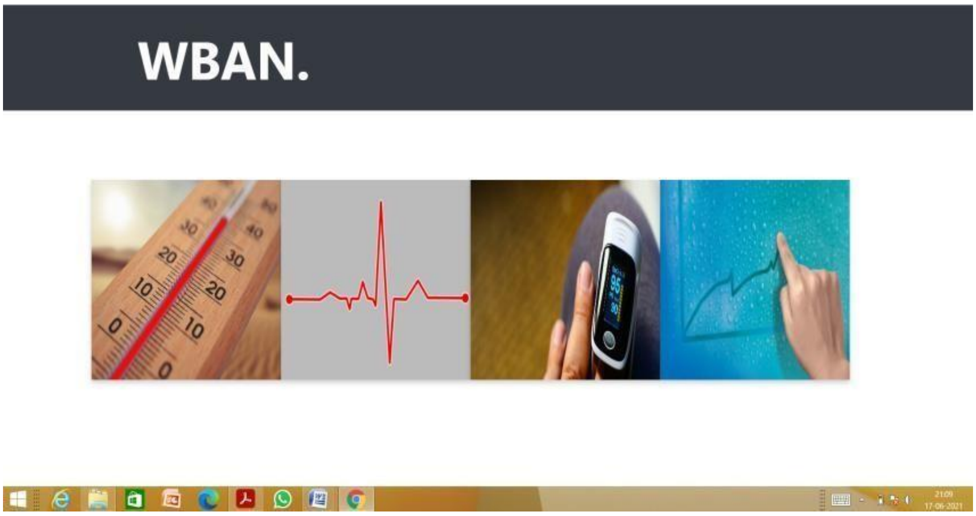

Fig6:Websitepage

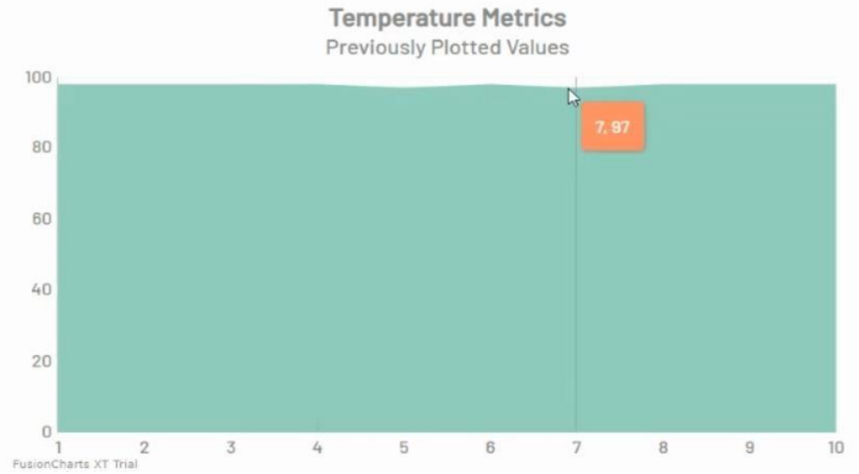

Fig 7: Plot oftemperaturereadingssensedfromthehumanbody

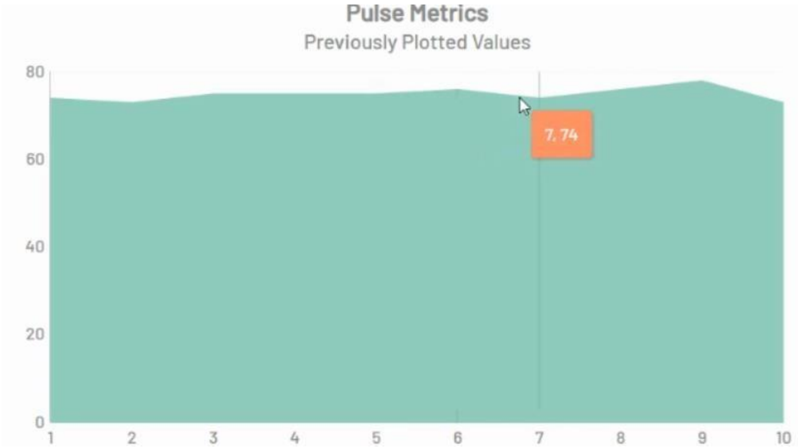

Fig8: Plot ofpulsesensedfromthehumanbody

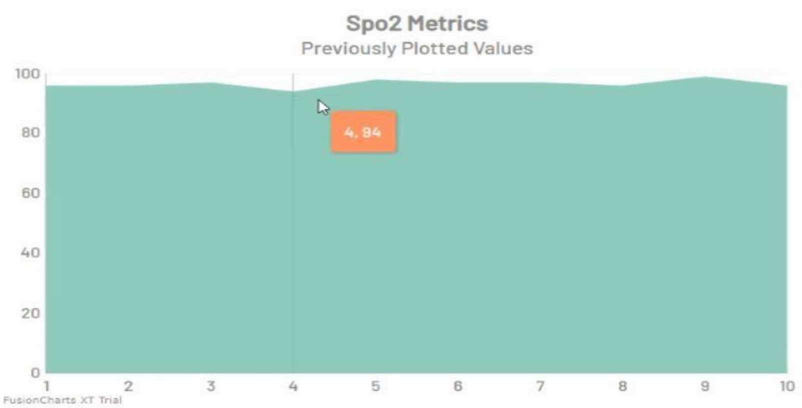

Fig 9: PlotofSpo2sensedfromthehumanbody

Fig10:Plot ofhumiditysensedinsidethepatient'sroom

4Conclusions

Thepatient'sbio-medicalvaluesweresuccessfullytransmittedandreceivedusingZigBee.ThenodeMCUmoduleconnectedtotheinternetanduploadedall of thevaluestothe real-timedatabase: firebase. The website retrieved all the data from the firebase and all the sensor values of apatient were visualized using graphs. The website could be accessed by any doctor globally, allacross the world. The patient's remote and continuous health monitoring system was designed andimplemented. The work resulted in an Internet of Things application with low power consumptionandlowcost,as wellasa securitysystemthatmaintainedvalueintegrity.

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