SWAST KHOJ: A real-time working prototype for vital healthcare monitoring System

Ramesh Saha (ramesh1saha@gmail.com)
VIT Bhopal University

Sanjeev Kumar Bharadwaj
Gauhati University, GUIST

Sohail Saif
Maulana Abul Kalam Azad University of Technology

Rajdeep Ghosh
VIT Bhopal University

Suparna Biswas
Maulana Abul Kalam Azad University of Technology

Sushanta Karmakar
Indian Institute of Technology Guwahati

Research Article

Keywords: IoT, real-time, healthcare, Prototype, WBAN,, QoS

Posted Date: May 9th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2890944/v1

Additional Declarations: No competing interests reported.

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[1]Ramesh Saha*, [2]Sanjeev Kumar Bharadwaj, [3]Sohail Saif,
[4]Rajdeep Ghosh, [5]Suparna Biswas [6]Sushanta Karmakar

[1,4] School of Computing Science & Engineering,
VIT Bhopal University, Bhopal, Madhya Pradesh, India
[2] Department of Information Technology,
Gauhati University, GUIST, Guwahati, Assam, India
[3,5]Department of Computer Science &Engineering,
Maulana Abul Kalam Azad University of Technology, West Bengal,
Kolkata, West Bengal, India
[6]Indian Institute of Technology, Guwahati, Assam, India
[1]ramesh1saha@gmail.com
[2]sanjeevkumarbharadwaj025@gmail.com
[3]sohailsaif7@gmail.com
[4]grajdeep.2014@gmail.com
[5]mailtosuparna@gmail.com
[6]sushantak@gmail.com

ABSTRACT

Internet of Things (IoT)-based health monitoring system is centred on continuous, real-time monitoring of the health of individuals. The emergence of IoT-enabled healthcare devices is rapidly changing the health infrastructure. IoT-enabled technologies can facilitate an effortless interaction among different devices and platforms. Smart health monitoring applications are a notable and important application in IoT and therefore, different types of IoT frameworks have been proposed by researchers. In the present work, an IoT–based real-time healthcare prototype has been implemented using unobtrusive heterogeneous sensor nodes to create a Wireless Body Area Network (WBAN) architecture. The prototype has been designed to collect vital parameters of the human body using heterogeneous sensors like: electrocardiogram (ECG), temperature, Saturation of peripheral oxygen (SPO2), and pulse rate. The collected data from the prototype shows the condition of the patient in a graphical user interface (GUI) in compliance with the Modified Early Warning Score (MEWS) medical guidelines. The prototype along with the user interface is named SWAST KHOJ**.** The data is periodically uploaded with the timestamp information on the local server**.** Further, the Quality of Service (QoS) parameter of the prototype is evaluated for different short-range communication like LAN (or Wire) , ZigBee, and Bluetooth in an indoor environment. The performance of the proposed prototype is evaluated on different communication technologies and it was observed that the proposed prototype requires an end-to-end delay of 0.514 ms, 0.62 ms, 0.417 ms and 1.92 ms for wire, Wi-Fi, ZigBee and Bluetooth respectively. Also, it is observed that the end-to-end delay of the proposed method is less than that of the previous works. Moreover, the throughput of the prototype using different communication technology has been evaluated for the prototype.

Keywords: *IoT, real-time, healthcare, Prototype, WBAN,, QoS.*

1. Introduction

One of the major reasons for considering the twenty-first century as a trendsetter is progress and expansion in domains such as wireless communication, micro-electromechanical systems technology, and integrated circuits. This advancement has in turn generated low-power, cost-effective, smart, and minuscule-sized, invasive/non-invasive micro and Nano-technology-originated sensor nodes which can be positioned tactically on or around the human body for the collection of various physiological signals. Consequentially, how healthcare services are applied and used in reality has witnessed a revolution. The modern-day healthcare applications' goal is to deliver early detection and prevention approaches to diseases in the patients concerned and outperform the traditional medical equipment used for curing illnesses.

Therefore, the Internet of Things (IoT) [1] [2] [3] [4] is the solution to information exchange problems, and it is the most powerful communication technique of the 21st Century. In an IoT Environment, every system is interconnected: from sensors to computing devices, and the data transfer, as well as storage of data, is highly maintainable and feasible. The most popular IoT applications are smart and remote healthcare. It offers a wide range of possible applications in healthcare, including remote and in-home health monitoring, chronic disease identification etc.

Health is essential for overall well-being and in the last few decades health deterioration has been rapidly increasing around the globe. In the coming three decades, the worldwide population of senior citizens is expected to more than double, approximating over 1.5 billion by 2050, this is based on the 2020 United Nations report [5]. With the advent of the Coronavirus disease 2019 (COVID-19), the world suffered a huge loss in its health and economic infrastructure. Accordingly, it has now become a necessity to take proper steps to ensure the well-being of individuals: both young and old. The advancement of technology in the field of information exchange has enabled the rapid transfer of data; this also provided us with various tools that promise to address the challenges faced in the field of healthcare.

The traditional healthcare systems do face quite a few limitations which may be curbed with the assistance of the new ICT-supported medical services for instance remote and pervasive healthcare [6]. The imminent health upheaval pulls researchers, scientists, and industries to find a solution for the situation. A new term 'eHealth' was coined and it was implemented by electronic processes. Nowadays, gradually healthcare is being expanded to 'mHealth', which provided signifies mobility of healthcare. For optimum utilization of wireless technologies, an innovative concept of Wireless Body Area Network (WBAN) has also evolved [7].

A WBAN application for monitoring healthcare is made up of a particular number of heterogeneous sensor nodes. WBAN sensor nodes can detect physiological indicators in the human body, such as blood pressure, heart rate, electromyograms (EMG), electrocardiograms (ECG), oxygen levels, body temperature, etc [8][9]. The data acquired is transferred to a Processing Unit where further analysis and data processing is done, the transmission of data can be done using various media: through the internet and without the use of the internet.

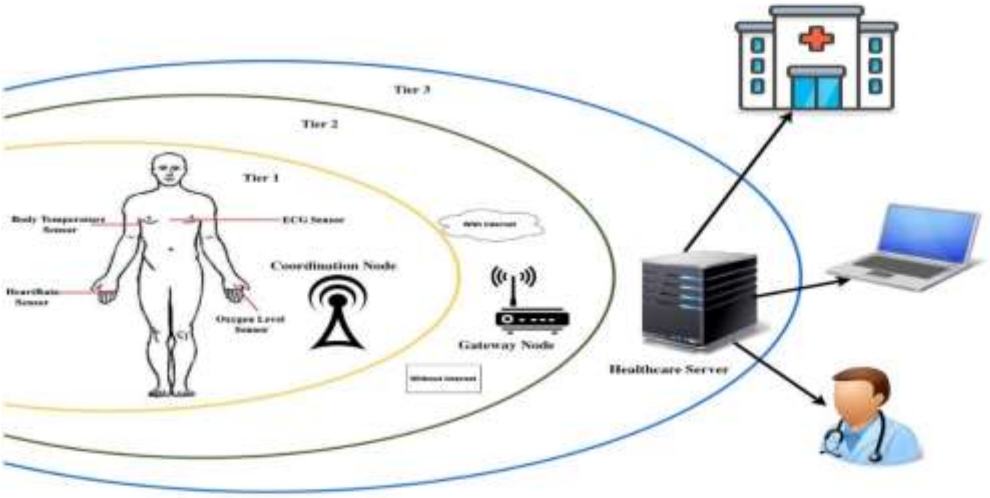

Figure 1. Wireless Body Area Network (WBAN) Architecture

WBAN architecture is shown in figure 1 [10] [11], the three tiers involved can be visualized, and in the final tier, the availability of medical facilities can be seen. In this architecture, Tier-1 collects vital information about the patient by sensor node and it is transferred to the medical server i.e., tier 3 for medical services with the help of tier 2.

In this paper, we have created a low-cost working prototype for healthcare monitoring. of WBAN employing different heterogeneous sensors for collecting vital signals of the human body such as ECG, Body Temperature, Oxygen Level, and Heart Rate [12] [13] in real-time. The sensor data is relayed to the microcontroller's central control unit (CCU) both are connected wired and wirelessly. The prototype is informed of the medical caregiver condition of the patient as per medical guidelines. It showed QoS parameters of different scenarios as communication using the Internet connection and without the use of the Internet connection. The organization of the paper is as follows. Section 2 presents the related works. Section 3, discusses the motivation and contribution of the work. The proposed working prototype, implemented in the lab environment represent in section 4, section 5 and section 6 respectively. Section 7 describes the case study with real-time stamp data collection implementation working prototype. In section 8. Illustrated QoS metric of implemented prototype. Finally, section 8 concludes the whole work.

2. Related Work

The development of a cost-effective solution for IoT-based smart healthcare that uses WBAN for environmental and physiological monitoring is a challenging task. In this section, illustrated and tabulated relevant research papers highlighting a comparative view of their contribution.

Saif et al. [14] implemented a wearable health monitoring system prototype using MySignals HW and Arduino which supports a variety of sensors: ECG Sensor, Body Temperature Sensor, SPO2 Sensor for measuring health vitals. Transmission latency has been measured in both wired (Ethernet) and wireless (Wi-Fi) communication modes to assess the prototype's performance. Saha et al. [15] designed and implemented a working prototype of WBAN using the DS18B20 Temperature sensor for Health Monitoring. The central control unit (CCU) of the microcontroller-based Arduino receives human or patient body temperature over a short distance using wired USB communication as well as using Zigbee for wireless communication. The CCU is located in a convenient position based on the system's ability to support the patient's maximal mobility and flexibility for monitoring. However, only body temperature has been considered only. Saleem et al. [16] designed a Smart and Cost-Effective Sleep Quality Monitoring System. In this system, the ambient and physical movements of a patient are monitored using several sensing units. Onasanya and Elshakankiri [17] implemented a Smart Integrated IoT based Healthcare System for Cancer Care. Various medical facilities such as health and wellness monitoring, remote monitoring system, operational services system, emergency services system, geriatric care, and remote medication are all part of the proposed system. Naik and Sudarshan [18] designed and implemented a system for healthcare monitoring. In the system, different sensors such as the ECG, blood pressure, temperature, acceleration, and pulse rate are employed to collect various health parameters with an interval for diagnosis and continuous monitoring. Kaur and Jasuja [19] designed a health monitoring system based on IoT using Raspberry Pi. The system monitors the person's health in real-time using Arduino, Raspberry Pi and sensors like the KG011 Heartbeat sensor and DS18B20 Temperature Sensor. This kind of health monitoring systems are effective for early detection and diagnosis of various severe diseases.

Gope and Hwang [20] designed a Body Sensor Network (BSN) based modern healthcare system. They have given a list of security characteristics that must be addressed in any BSN-based IoT-based healthcare system as well as how to enforce security in our BSN-Care model to achieve all of the necessary security attributes. Wannenburg and Malekian [21] designed a health-monitoring system that supports mobility. The system is used to measure and monitor the patient's vital physiological signals, as well as interpret and monitor the data. Abnormal conditions are identified and forwarded to the medical team for further study and analysis. Medical standards are followed to correctly measure all the relevant parameters. The system can provide accurate medical feedback to the user and correctly diagnose the condition before alerting a doctor to prescribe the next step. Haghi et al. [22] designed a healthcare platform for the real-time monitoring of physiological parameters and ambience. The system is designed into a wrist-worn prototype for ambience monitoring. It uses a Gas sensor, microphone, and UV Index module to monitor the environment's ambience. The system also describes how physiological and ambient conditions play a huge factor in the health of an individual. Pawar [23] designed a system which monitors physical parameters of the human body like a heartbeat, body temperature and orientation. Data from the module is transferred to the doctor's mobile phone through GSM, allowing the system to be used in rural or remote areas. This system is a great in-home health-monitoring equipment that can monitor senior citizens. Chen [24] developed a web-based medical treatment model. The proposed system uses various sensors: MLT1010 pulse transducer and piezoelectric sensor, which is utilised to remotely study and analyse the patient's health state. The patient's data from the sensor units are transferred to a web model, where the patient's vitals are monitored and observed. Based on the observations, the patient's current health condition are determined.

In the above literature review, we observed that biological sensor-based healthcare systems can be used to monitor the normal and abnormal conditions of patients. In this paper, we have introduced a working prototype entitled "SWAST KHOJ" to monitor patients in critical conditions as well as normal conditions depending upon the medical guidelines, The summary of the literature survey is presented in table 1.

Table 1: Comprehensive summary of related works

Authors and Year	**Proposed prototype or Framework**	**Used hardware component**	**Used software component**	**Used communication protocol**	**Performance parameter**	**Application area**
Saif et al. [14], 2021	A wearable health monitoring system prototype	My signal kit (HW), ECG Sensor, Body temperature Sensor, SPO2 Sensor	Arduino IDE	Ethernet and WiFi	End-to-end delay of wired connection and wireless connection	Realtime health monitoring
Saha et al. [15],2021	A temperature sensor (DS18B20) based working prototype	Arduino and DS18B20 Temperature Sensor	Microsoft Visual studio and WAMP Server	Shielded USB cable and Zigbee connection	The system works properly the way the authors have designed for collecting body temperature, transmitting over wireless communication and analysing data after receiving.	Real-time health fever monitoring system and get satisfactory output temperature after comparison with the readings of a conventional medical thermometer
Imran et al. [16], 2020	A cost-effective sleep monitoring system that may be utilised for patients at home or in hospitals and can track them for more than one day/night Sensors are used in the proposed system, which is readily available on the market.	ADXL345 Accelerometer, MAX30100 the pulse oximeter, MAX9814 microphone amplifier	Android Application	LAN or Internet	Analysis of patient sleep,	Sleep Quality Monitoring system in healthcare
Adeniyi Onasanya and Maher Elshakankiri[17],2019	A Cancer Care Smart Integrated IoT Healthcare System. Here a patient can be tracked	Smart device and GPS	Web interface	NFC, BLE, ZigBee, Internet,	Network resources, device heterogeneity, security & devices vulnerability	IoT- based medical system to enhance treatment of monitoring of cancer patient

	using a smart device and GPS			Cloud service		
Naik et al.[18],2019	Heterogeneous sensors node of WBAN are used for a few seconds to capture body health parameter information for the diagnosis	ECG Sensor, Blood Pressure Sensor, Temperature Sensor, Acceleration Sensor, Raspberry pi	Android Application	Bluetooth, Internet 3G	By using thermistor register measure human body vital parameter like temperature.	A system for healthcare monitoring
Jasuja et al.[19],2017	Real-time monitoring to keep track of the person's health. Diseases may be detected and treated quickly, and errors will be reduced because data is stored in the cloud without the need for human intervention.	G011 Heartbeat sensor, DS18B20 Temperature Sensor	IBM Watson platform	Shielded USB Cable, WiFi Dongle	Measure the performance of temperature and pulse rate	Health monitoring systems
Prosanta Gope and Tzonelih Hwang[20], 2016	A Secure IoT-Based Modern Healthcare System Using Body Sensor Network	Electrocardiogram (ECG), Electromyography (EMG), Electroencephalography (EEG), Blood Pressure (BP)	Server-Client Network	3G/CDMA/GPRS	Here, provides a list of security attributes that must be addressed in any BSN-based IoT-based healthcare system, as well as for instructions on how to enforce security in our BSN-Care model to achieve all of the required security attributes.	Secure smart Healthcare
Johan Wannenburg and Reza Malekian [21],2015	A health monitoring on go, with different sensors attached to a person's body, collects vital data from the patient and measures it according to medical standards. Here, an emergency is considered and the system	Temperature sensor, heart rate sensor, SPO2, blood Pressure, oscilloscope	Android application	Bluetooth, Wi-Fi, Internet	Measure the accuracy of body temperature and Blood pressure,	A mobile-based health-monitoring system

	tracks the medical health condition of the patients					
Haghi et al. [22], 2015	A real-time physiological and environmental monitoring tool for healthcare. The technology is being developed as a wrist-worn prototype for environmental monitoring.	Gas sensor, microphone, UV Index module	Android Application	Not specify	Healthcare platform for physiological and ambient real-time monitoring performance analysis	Healthcare
Pawar et al.[23],2014	A remote health-monitoring system that collects patient vital data like heart rate and sends it to the doctor's mobile phone via GSM module, put to use in rural areas.	Heart rate sensor	Arduino IDE and C/C++	GSM module communication Module	Heart rate measure was performed and the error percentage has been calculated	patients and the elderly health monitoring system
Chih-Ming Chen[24],2011	Web-Based analysis system that can continuously analyse human pulse data remotely and alert caregivers in the event of an emergency.	MLT1010 pulse transducer piezoelectric sensor	Web Browser, Server-Client Network	Wire connection, Wireless and Internet	Human pulse signal operation performance Analysis	Web-based healthcare scenarios

3. Motivation and Contribution

In the current world, healthcare plays the most vital role in people's lives, being able to get a proper status on the current health condition of an individual has become a necessity. Health monitoring, as well as health care, require frequent visits to the hospital and time-to-time diagnosis which not only requires time but also causes mental exhaustion to people.

In an under-development country like India, the number of doctors is rising by 2000 only out of 10000 and the number of patients has also increased exponentially [25][26]. In the present scenario, i.e. Pandemic, patient handling has become a difficult task since healthcare workers are also getting affected by this situation.

The Internet of Things (IoT) is one of the best solutions to this current problematic scenario as it enables the technologies required for remote healthcare systems. Being remote is not the only requirement, being accurate and highly mobile is also important.

Saha et al. [15] and Saif et al. [14] implemented a real-time working prototype for handling vital information of the patient using heterogeneous sensor nodes and a hardware kit respectively. The authors gave some limitations pointed out in the conclusion. In this context, we want to develop and extend a real-time working prototype to handle the patient's condition and reduced the doctor's burden.

The main contribution of the work is as follows:

(i) Low-cost easy-to-use working prototype for continuous monitoring of human vital health conditions.

(ii) End layer of WBAN or medical server analyzes the health condition of the patient using MEWS medical score and GUI representation is used to display the real-time health condition.

(iii) Different communication techniques are considered for data transferred body information from the human body to the medical server and its performance comparison is done.

(iv) The prototype is shown improvement in Quality of Service (QoS) like end-to-end delay and throughput of data transferred. Even the prototype gets a better result when compared with costly hardware kit-based work as well as previous work.

(v) Finally, we have done a case study to take patient real-time data using the prototype and collected real-time data from the human data body as a test case and analyzed them as per medical guidelines to take a decision. Then this data is stored on the medical healthcare server for future use.

4. Proposed Working Prototype

The proposed system is based on IoT-based WBAN architecture, here, body vital information is collected using ECG, Pulse, SpO2 and Temperature sensors. This data is transmitted to the Edge Device through different transmission media like Ethernet Cable Wi-Fi, ZigBee and Bluetooth. The edge devices are capable to decide if there is any emergency condition as per medical guidelines otherwise the Edge Device forwards the data to a data store which keeps the record of the sensor data for further analysis. Figure 2. Shows the flow diagram of the proposed system.

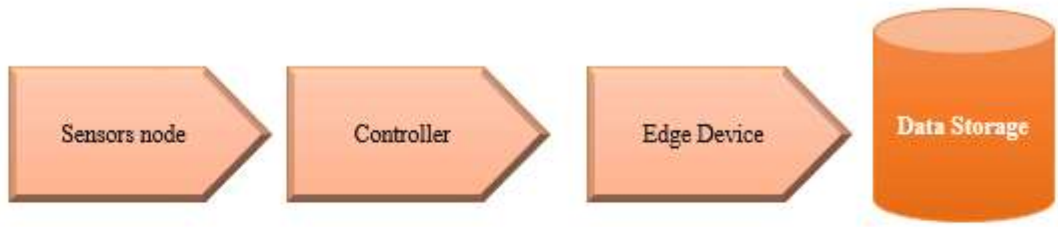

Figure 2: Flow diagram of the proposed system

Figure 3, shows the different stages of the proposed system. The system includes different stages a) data Acquisition b) Data Processing c) Data Transmission d) Data Storage.

Figure 3: The stages in the Proposed System

The proposed of proposed system is described as follows:

a) **Data Acquisition:** In this stage, the sensitive data of patients from the sensors are acquired by the Central Control Unit (CCU).

b) **Data Processing**: During this stage, the acquired data is processed by the key-value pairs i.e., a suitable algorithm depends upon conditions before transmitting it.

c) **Data Transmission:** At this stage the data transmission takes place, and the processed data is transmitted to the Edge Device using different transmission media like Ethernet Cable, WiFi, Zigbee and Bluetooth.

d) **Data Analysis:** The received data is analyzed to check a patient's health condition and a real-time report is generated which is accessible by authorized people like doctors, nurses or caregivers.

e) **Data Storage:** The data is required to be stored for further analysis and references, this stage in the IoT application ensures data storage for the patient's vitals.

In the proposed working system, real-time different heterogeneous sensor data are collected and sent to the server through wired and wireless connections. Therefore, the prototype is considered patient mobility in the indoor and outdoor environment. The different scenarios of data transmission to the central processing unit (CCU) describe as:

4.1. Scenario 1: With an Internet connection

Nowadays, the internet is the most popular communication for data transfer and 3G/4G/5G data communication is established almost worldwide. Therefore, in the outdoor environment, data can be easily transferred to the medical server through the Internet. But it can increase the cost of healthcare. In this scenario, vital information about the patient is collected by the sensors like ECG, Oxygen Level and Pulse Rate, and it is transmitted to the monitoring devices through the internet connection. Here, Raspberry Pi is used as the Central Controller Unit (CCU) of the proposed system. Sensor data can be assessed by the doctor or caregiver for health analysis of the patient, a real-time report is also sent to the authorized people. In this system, authorized people like doctors, nurses or caregivers can access the data from a web browser as shown in figure 4.

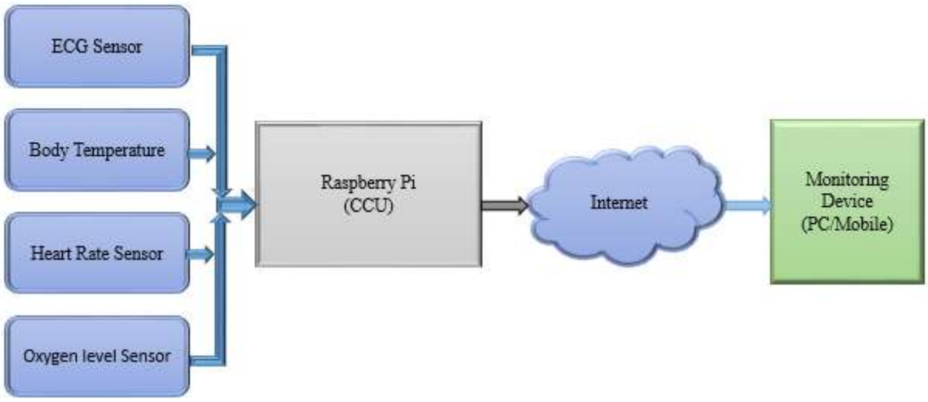

Figure 4: Data Transmission using Internet connection

4.2 Scenario 2: Without an Internet connection

Here, focuses on the transmission of data without the use of an internet connection. We have considered an indoor environment and an internet connection is not required. A lot of short-range communication methods are available to transfer vital data of the patient from the sensor to the medical server (a) using a wired connection (Ethernet), (b) using Wi-Fi, (c) using Zigbee and (d) using Bluetooth, as shown in figure 5.

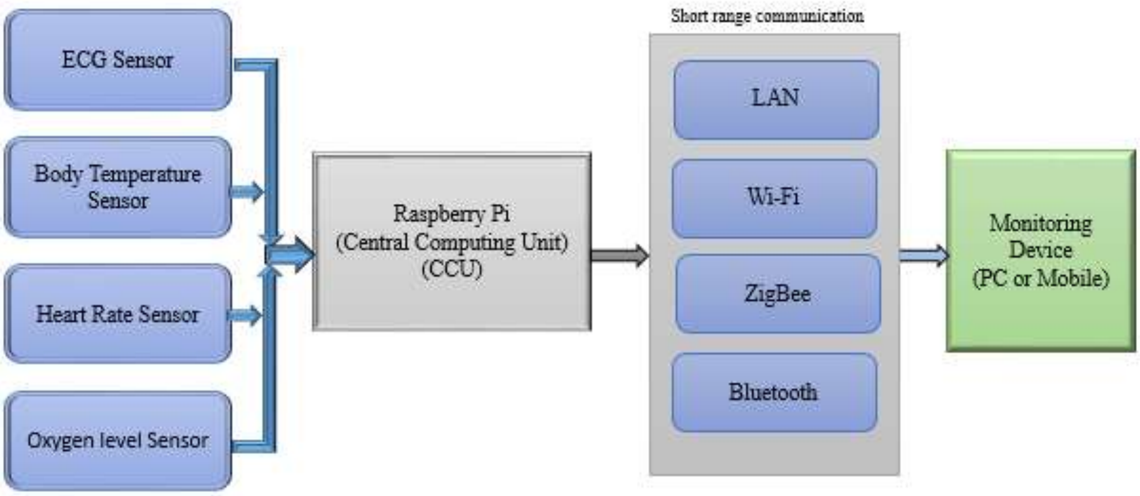

Figure 5: Data Transmission using without Internet Connection

4.2.1 Scenario 2a: Using Wired Connection

The wired connection has been set up using twisted-pair Ethernet Cable (CAT 5e) with RJ45 end-connectors which connect the Raspberry Pi directly to the patient monitoring system. The CAT5e cable supports 1 Gbps transfer speed up to 100m. The data transmission takes place through a wired connection. The data from the sensor can be accessed by a doctor, nurse or caregiver for health analysis of the patient on the monitoring device.

4.2.2 Scenario 2b: Using Wi-Fi

In our IoT Lab Environment, a Wi-Fi hotspot has been set up which acts as the gateway for the establishment of a local network. Raspberry Pi connects to this Hotspot and our monitoring device connects to the same network. Once the connection is established, the various heterogeneous sensor values: ECG, Body Temperature, Oxygen and Pulse rate are transmitted by the Raspberry Pi Server and vital data is stored in the medical server which can be accessed on the monitoring device by a doctor, patient and caregiver. This considers the patient's indoor mobility.

4.2.3. Scenario 2c: ZigBee Communication

In ZigBee communication, two ZigBee units are used, where one acts as the receiver and the other as the transmitter. Once the connection is established, the data is received serially and stored in the medical server. The data can be accessed on the monitoring device by a doctor, patient and caregiver. Zigbee communication is shown in figure 6, where used two ZigBee units.

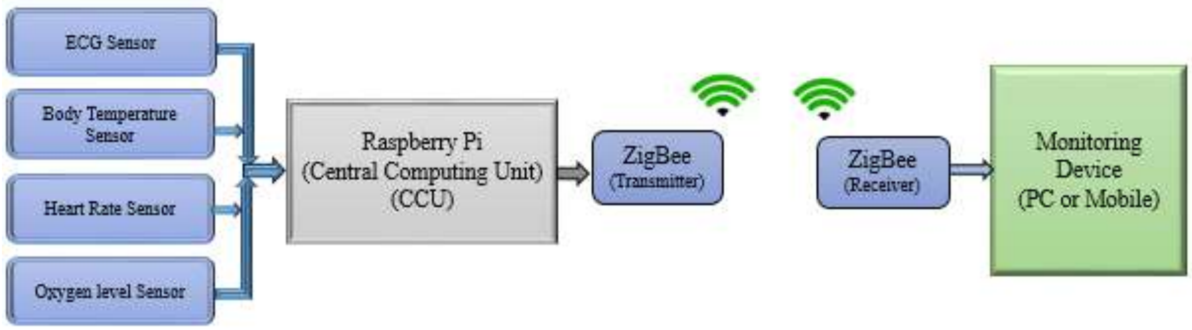

Figure 6: Data Transmission using ZigBee communication

4.2.4. Scenario 2d: Bluetooth Communication

Bluetooth is the most popular short-range communication protocol for transmitting data over short distances between fixed and mobile devices. Using Bluetooth, the receiving unit (HC-05) is attached to an Arduino with microcontroller ATmega328. Raspberry Pi has built-in Bluetooth which is acting as the transmitter in this scenario. Once the connection is established, the data is received serially and the same collected data is stored in the medical server, as shown in figure 7. The data can be accessed on a monitoring device by a doctor, patient and caregiver for a patient’s health analysis.

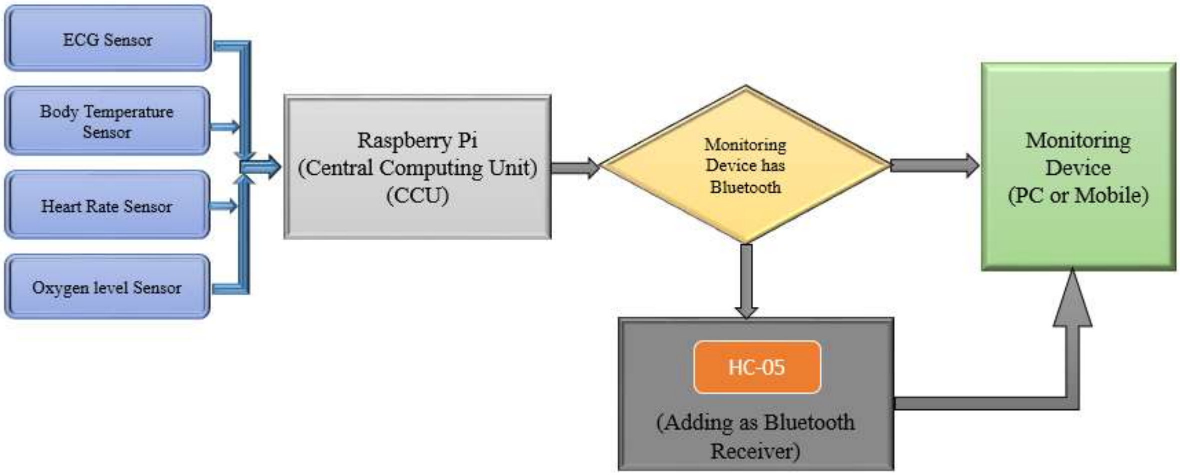

Figure 7: Data Transmission using Bluetooth protocol

5. Component required for Implementation

In the IoT lab environment, this working prototype is implemented using different hardware and software components for interfacing and collecting patient vital information from the sensor to the medical server or storage.

5.1. Used Hardware component

The proposed system requires different hardware components such as sensors, microcontrollers as well as communication media for data collection and transmission table 2. Describes different hardware components used for the development of the prototype.

Table 2: Used hardware components for implementation working prototype

Sl. No	Component name	Description	Purpose
1	Raspberry Pi 4 [27]	The Raspberry Pi Foundation, along with collaborators, developed a series of miniature single-board computers (SBCs), which are named Raspberry Pi. Today, different versions of Raspberry Pi are available, and Raspberry Pi 4 Model B is the version used here. It features a 1.5 GHz 64-bit quad-core ARM Cortex-A72 processor, on-board 802.11ac Wi-Fi, Bluetooth 5, full gigabit Ethernet (throughput not limited), etc among other features. A USB-C port is used to power the Pi 4. Raspberry Pi requires an Operating System to function and it works like a computer where input is digital data.	Raspberry Pi 4 plays the Central Control Unit (CCU) that sends patient's vital information to the health monitoring devices. The different sensors: SPO2, Heart Rate Sensor, ECG Sensor, and Body Temperature sensor are connected to the Raspberry PI's General Purpose Input/output Pins (GPIOs).
2	Arduino Uno [28]	The Arduino Uno is a microcontroller board that uses the ATmega328P microcontroller. It contains 14 digital input/output pins, 6 analogue inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power jack, an ICSP header, and a reset button.	Arduino Uno is used here to get the otherwise directly inaccessible Bluetooth data.

		It can be powered through the USB or using the power jack.	
3	DS18B20 Temperature Sensor [15]	The DS18B20 digital thermometer measures temperatures from 9 to 12 bits in Celsius. The DS18B20 communicates with a CPU through a 1-Wire bus. Furthermore, the DS18B20 can draw power directly from the data line (parasitic power), obviating the requirement for an additional power supply.	The Body Temperature sensor (DS18B20) is used to measure the body temperature of the patient. The sensor is connected to the GPIO Pin of the Raspberry Pi 4 directly.
4	ECG Sensor [29]	An electrocardiogram (ECG) monitors the electrical activity of the heart to examine its functionality. The ECG (Electrocardiogram) sensor monitors the passage of electrical impulses through the heart muscle over time by utilising conductor type electrodes. It can provide information regarding heart's reaction to physical exertion in both resting and ambulatory patients.	The ECG sensor sends the ECG data to the pcf8591 ADC/DAC analogue-digital Converter which connects it to the GPIO Pin of the Raspberry Pi 4.
5	MAX30100 Pulse Oximeter [30]	A pulse oximeter detects a person's blood oxygen saturation by placing an LED and a photo-detector against thin skin on the body, such as a fingertip, wrist, or earlobe.	MAX30100 Pulse Oximeter measures both oxygen levels as well as the heart rate of the patient. The sensor is connected to the GPIO Pin of Raspberry Pi 4.
6	ZigBee (Xbee) [31]	XBee modems are used to build wireless point-to-point or mesh networks. They have error correction, can be set up with AT commands, and can generate wireless serial links easily.	One Xbee unit is connected to the Raspberry Pi 4 and the other to the Health monitoring device (in this case Laptop). The Xbee units are first paired then the patient's vital information is transmitted from the Raspberry Pi 4 and received by the monitoring device.
7	Bluetooth Module (HC-05) [32]	The HC-05 is a Bluetooth module that is used to communicate wirelessly. This module can be used either as a master or a slave. The module communicates using USART at a 9600 baud rate, making it effortless to connect to any microcontroller that supports USART.	Raspberry Pi 4 has inbuilt Bluetooth but the monitoring device does not have Bluetooth installed. HC-05 is a Bluetooth module that is connected to Arduino Uno. A connection is established between the server and the monitoring device with Arduino Uno acting as a serial bridge.
8	PCF8591 ADC/DAC Analog to Digital Converter [33]	The PCF8591 is an 8-bit CMOS data acquisition device. Since Raspberry Pi operates only on digital data, PCF8591 helps in the use of sensors like ECG sensors which require an Analog input.	Raspberry Pi 4 is a digital device and exclusively works on digital data. So, PCF8591 ADC/DAC Analog-Digital Converter is used to input Analog data. PCF8591 is connected to the Raspberry Pi 4's GPIO Pins.
9	Tenda N301 Wireless-N300 Easy Setup Router [34]	Standard and Protocol IEEE 802.3/3U IEEE 802.11n/g/b, 10/100Mbps LAN Port. Fixed 5dbi Omni Directional antennas, 300Mbps wireless speed ideal for interruption sensitive applications.	Tenda N301 is the router that helps us create the Hotspot required for wireless communication in our IoT Lab Environment.

5.2. Used Software Component

The different hardware that was used in the system required different software components to enable the proper interface, understanding ability, and connection establishment. Table 3 shows, the different software's and APIs put into use in the proposed system.

Table 3: Used software applications for implementation working prototype

Sl.	Software Used	Description	Purpose
1.	Raspbian Buster OS [27]	Raspbian OS is based on Debian Linux 10, with the Linux kernel version 4.19 and the GCC compiler version 8.3.	Raspberry Pi requires an Operating System to function, the operating system used here is Raspbian Buster.
2	Arduino IDE [28]	The Arduino IDE (Integrated Development Environment) is a software development environment that allows to use Arduino and hardware to upload and communicate. It's used to write and upload programs to Arduino-compatible boards, as well as other vendor development boards with the support of third-party cores.	The Arduino IDE is used to write and upload the required code to enable the use of HC-05 through a serial link, in Arduino Uno.
3	Visual Studio Code [15]	Microsoft's Visual Studio Code is a source-code editor. Visual Studio Code is a lightweight yet capable source code editor for Windows, macOS, and Linux.	Visual Studio Code editor is used here to write our code. It has a clean interface and multiple tools to aid with the development
4	ZigBee (XBee) Configuration and Test Utility (XCTU) [31]	The XBee Configuration and Test Utility (XCTU) allows communication with digital radio frequency (RF) devices. The application's built-in features facilitate simple setting up, configuration, and testing of digital RF equipment's.	The XCTU application enabled set up of Xbee units in receiver and transmitter mode for data transfer.

6. Implementation of Working Prototype in LAB environment

The working prototype has been implemented and developed at the IoT lab of Gauhati University, India. Two scenarios are considered for the experiments: one is with the presence of an internet connection, where the data from the different heterogeneous sensors: ECG sensor, pulse oximeter and body temperature sensor from the patient who is in a mobile or static position are transferred from the Raspberry Pi (health system) to the monitoring device (PC/mobile) through the web. Here, the data can be retrieved and viewed using a web browser by a caregiver, or doctor. Another scenario is without the presence of an internet connection, where a wired connection using a twisted-pair Ethernet cable and different wireless communications such as Wi-Fi, Zigbee and Bluetooth are used. The data is transmitted over the different communication media from the sensors through the Raspberry Pi and accessed on the Monitoring device as shown in figure 8.

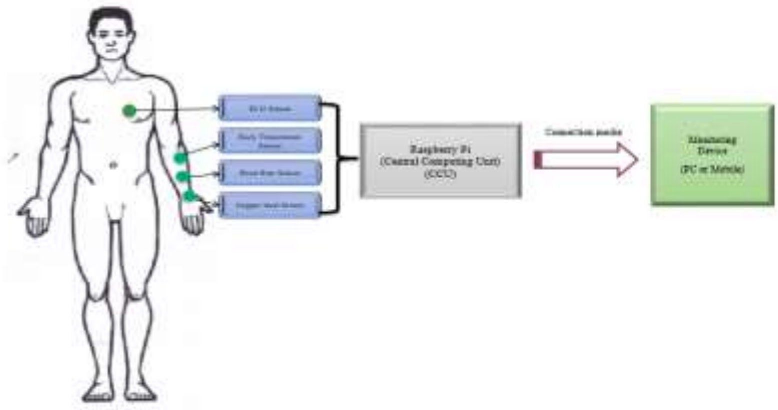

Figure 8: Work Flow Diagram of the Prototype

6.1. Scenario 1: With an internet connection

In this scenario, the sensors are connected to the Central Control Unit (here used Raspberry Pi) using General-Purpose input/output (GPIO) Pins. The data acquired by the Raspberry Pi is transmitted through an internet connection. It is monitored using (here used PC or Mobile) and data is stored in the cloud server (local cloud server used for experiment purposes) which can be accessed through the web browser. In figure 9, it is shown that the accessed data can be viewed on the web browser by authorized people like doctors, nurses or caregivers to further evaluate a patient's health status.

Figure 9: Data Viewed on Web Browser through Internet Connection

6.2. Scenario 2: Without an internet connection

In this scenario, internet connectivity is not used to transfer the data from Raspberry Pi to the monitoring device without using internet communication. Four different short-range communication mediums are used here (a) Wired connection using Ethernet Cable and different wireless media like (b) Wi-Fi (c) Zigbee communication and (d) Bluetooth.

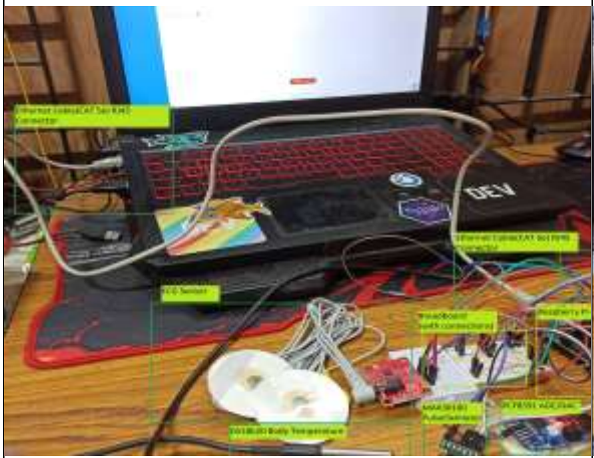

Figure 10: Connection of the working prototype with Ethernet Cable(CAT 5e)

Figure 11: Using Wireless (WiFi) for data transmission

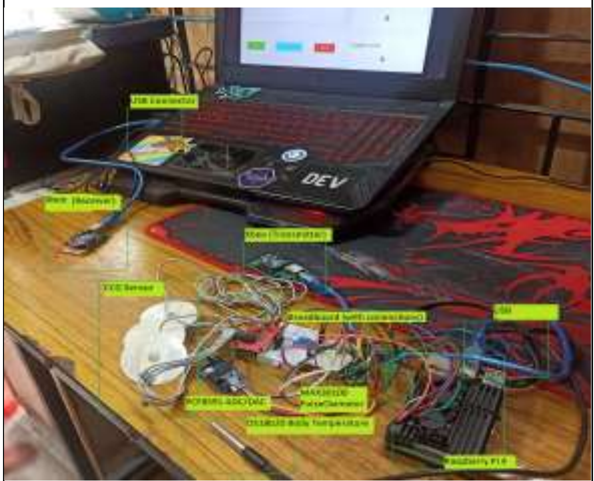

Figure 12: Zigbee Communication

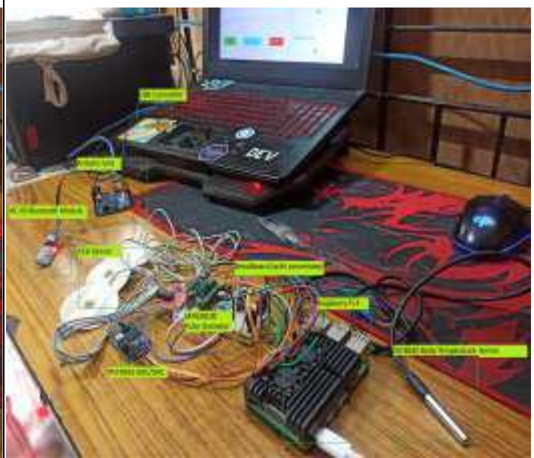

Figure 13: Bluetooth module (HC-05) with Arduino Uno and Raspberry Pi

In each scenario, the monitoring device here has an application where the address and port are entered along with the username of the patient, when the required parameters are correctly entered, the data transmitted are visible in the monitoring device's dashboard. This data is available to the patient, doctor or caregiver. In the case of a wire connection twisted-pair Ethernet cable, CAT 5e is connected to the RJ45 socket of the Raspberry Pi and the other end is connected to the RJ45 socket of the PC as shown in figure 10. In figure 11, the hotspot is responsible for the creation of a local network i.e. through Wi-Fi, where both our Raspberry Pi and Monitoring device (here PC) are configured to connect to it. Here, we see that no cable is used to connect the Raspberry Pi to the Monitoring system and it provides patient mobility. Similar to the Wi-Fi module, Figure 12 shows the use of the Zigbee communication protocol to make a connection between the Raspberry Pi and the monitoring device (PC). Here, the encoded sensor data are sent from the Raspberry Pi through the ZigBee (Xbee) unit using serial communication at the baud rate of 9600. Figure 13 shows the use of a Bluetooth module for data transmission. Here, Raspberry Pi 4 has built-in Bluetooth (BCM2711) version 5 protocol, so no external Bluetooth device is required to be attached. But our monitoring device (here PC) had no Bluetooth device so a Bluetooth module HC05 is used. Bluetooth module HC05 is connected serially with Arduino Uno which is connected to the monitoring device (here PC) through a USB cable.

For all scenarios. Patient vital information is stored in a database on the local server. Every patient has been assigned a unique username, and the data collection is done based on the “date of monitoring”. Every data entry has the collected sensor values: ECG value, oxygen level, pulse rate, and body temperature. These data are stored in the monitoring device database and cloud server for future reference.

7. Case Study of Working Prototype

The health data is visualized using the Graphical User Interface (GUI) of the proposed system. The interface and the GUI of the proposed system enable the authorized patient, doctor, nurse or caregiver to get access to the transmitted sensor data. This data is used for further analysis of a patient's health condition as a predefine health condition. The name of this visualization system or Graphical user interface (GUI) is “SWAST KHOJ”.

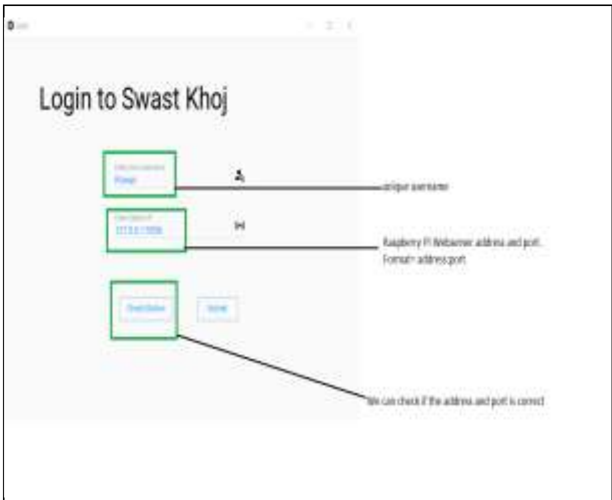

Figure 14: Login on Monitoring Device

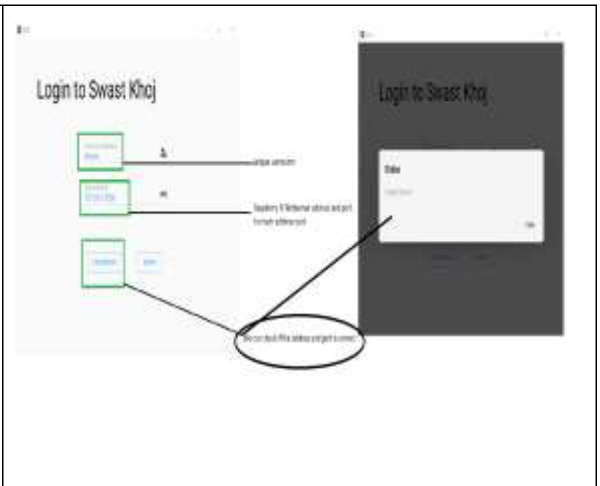

Figure 15: Checking that address and port is correct

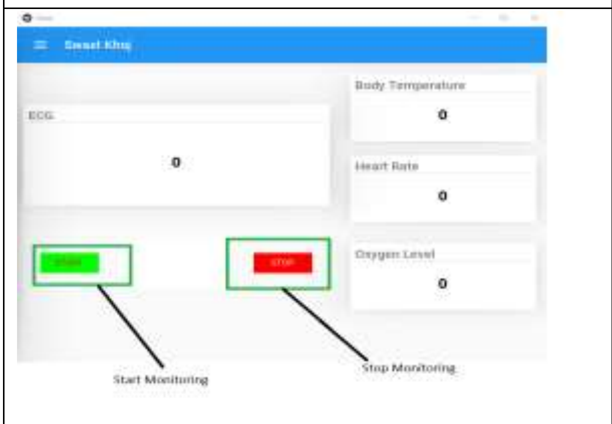

Figure 16: Dashboard of the Application

Figure 17: Vitals monitoring after connection

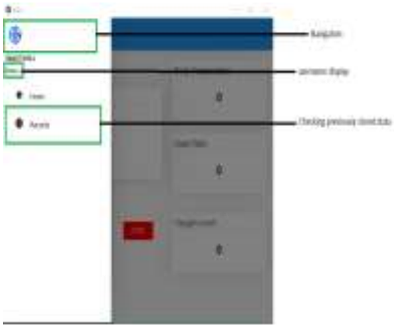

Figure 18: Navigation within the application

Figure 19: Data Stored in the database

In figure 14, the Home-Screen is the first screen that the user sees. There are two required fields to be filled before proceeding into the main application: The field "username" is the field which asks the user to enter his/her username, this field is necessary as it separates one user from another. Once the required fields are filled, it is necessary to click on the check station button to ensure that our data in the fields are correctly entered, this performs a response check and informs us if our Medical Server is Online, as shown in figure 15. After, clicking on Submit, we proceed to the dashboard of the application where the patient's vital data can be monitored with the click of the START Button. Also, the monitoring process can be stopped by clicking the STOP button, as shown in figure 16. Once the START button is clicked, all the sensors start sending the data to the monitoring device at a delay of 2 seconds. The various sensor data being displayed can be seen in figure 17. The application interface also enables the patient, doctor, nurse or caregiver to navigate between the dashboard and record pages, as shown in figure 18. The record page is displayed the stored patient health records. This data is stored into the healthcare server for a patient's health analysis by a doctor, nurse or caregiver. The error-free vital information of the patient is stored into the backend database or server shown in figure 19. Here have collected health data from several volunteers using the Hardware Prototype i.e. SWAST KHOJ. The data was collected from a different times interval and different place of environment. A few of the data samples have been shown in table 4.

Table 4: Real-time sample data collection using SWAST KHOJ prototype in Lab Environment

Volunteers	**TIme Elapsed (mm:ss)**	**Heart Rate**	**SPO2**	**Body Temperature**	**ECG Value**
Volunteer - 1 Age: 21 Gender: Male	00:02	81	96	37.1	107
	00:04	85	96	37.0	108
	00:06	82	95	37.2	107
	00:08	83	96	37.1	107

Volunteer - 2 Age: 15 Gender: Male	00:02	75	98	37.0	115
	00:04	77	97	37.1	112
	00:06	74	97	37.3	114
	00:08	76	96	37.1	110
Volunteer - 3 Age: 48 Gender: Female	00:02	80	96	37.6	112
	00:04	78	96	37.1	113
	00:06	82	96	37.3	112
	00:08	81	95	37.3	115
Volunteer - 4 Age: 51 Gender: Male	00:02	77	95	36.8	114
	00:04	76	97	36.9	113
	00:06	77	96	37.1	112
	00:08	77	95	36.7	112
Volunteer - 5 Age: 27 Gender: Female	00:02	86	96	37.2	118
	00:04	81	97	37.3	117
	00:06	82	95	37.2	115
	00:08	82	96	37.2	116
Volunteer - 6 Age: 35 Gender: Male	00:02	87	94	38.6	115
	00:04	88	96	38.6	117
	00:06	88	96	38.4	119
	00:08	86	97	38.5	118
Volunteer - 7 Age: 42 Gender: Male	00:02	86	95	37.2	112
	00:04	87	96	37.2	111
	00:06	82	97	37.1	112
	00:08	85	97	37.2	113
Volunteer - 8 Age: 26 Gender: Female	00:02	85	96	37.1	110
	00:04	87	96	37.2	112
	00:06	88	96	37.1	111
	00:08	86	95	37.0	112

Volunteer - 9 Age: 33 Gender: Female	00:02	87	95	37.3	113
	00:04	86	96	37.2	110
	00:06	86	97	37.0	112
	00:08	85	97	37.3	112
Volunteer - 10 Age: 24 Gender: Male	00:02	79	96	37.2	111
	00:04	75	95	37.1	112
	00:06	81	97	37.1	111
	00:08	83	97	37.2	110

The dashboard of the application also performs an analysis of a patient's health status and provides alerts based on the received data. This monitoring report enables the patient to understand the current health condition, using Delphi and nominal group condenses were employed for a multidisciplinary approach to derive a contextual suitable MEWS from an existing UK-MEWS which is based on Modified Early Warning Score (MEWS) as depicted in table 5 [35] . Here, the physiological parameter and range of the MEWS cut point were defined. Each data was partitioned for recording the actual data. Here each component of MEWS has an associated score ranging upper to lower from 1 to 3, indicating the magnitude of deviation from the 'Normal ' range (defined as 0). Both the single-parameter and multi-parameter track-and- trigger systems were incorporated.

The implemented proposed prototype will take a decision when emergency conditions happened. The MEWS score chart 0= no action will be taken; 1= re-check after some time and report if no improvement; 2= check after a small time and report immediately if no improvement; 3= critical situation and report to the caregiver/ nurse/doctor immediately to take action. The implemented prototype is parallel connected to the patient vital information and checked the health condition of the patient. Normally ECG signals have five kinds of waves i.e. P.T.Q.R and S wave. RR, PR and QT intervals are used for checking various heart diseases. The normal range of the PR, RR, QT and QRS as per medical guidelines are listed in table 6 [14] [36][37]. Therefore, the proposed SWAST KHOJ has implemented a real-time working prototype of the Wireless Body Area Network (WBAN) to handle emergency healthcare situations.

Table 5: Medical guidelines (MEWS Score Chart)

Parameter	**3**	**2**	**1**	**0**	**1**	**2**	**3**
Heart rate(bpm)	----	<40	40-50	51-100	101-110	111-129	>=130
SPO2	<85	85-89	90-92	>=93	------	-----	------
Temperature (C)	----	<35	---	35-38.4	-----	>=38.5	-----

Algorithm

Input: Heart Rate (HR), SpO2 Value, Body Temperature(BT), Electrocardiogram (ECG)
Output: Health condition of the patient

```
 Step 1:  input = = (ECG,HR, SpO2, BT)
 Step 2:   while (  input)
                  Collect Sensor data ( HR,BT, SpO2 and ECG) from SAWAST KHOJ prototype
Step 3:         if  ECG value !== (RR, PR,QT, QRS  Normal)
                      Make the patient the condition is critical and send alert to the doctor/ nurse/ caregiver
 Step 4:        elseif HR < 40 or HR >=130 then
                   Set Patient's condition as critical and alert the doctor/nurse/caregiver
 Step 5:          elseif BT < 35 or BT >=38.5 then
                   Set the patient's condition as critical and alert doctor/nurse/caregiver
  Step 6:         elseif SpO2 < 85  then
                   Set the patient's condition as critical and alert doctor/nurse/caregiver
  Step 7:         elseif (51<HR<100 and 35<BT<38.4 and SpO2 >=93) or (ECG value == (RR, PR,QT, QRS
                        Normal)
                   Set the patient's condition as normal
   Step 8:      endif

  Step 9:   end while
```

Table 6. ECG signal Normal Range as per medical guidelines

Parameter	Normal Value (in second)
RR	0.6-1
PR	0.12-0.20
QT	0.32-0.44
QRS	<0.12

Figure 20 shows that one patent data which is collected from the SWAST KHOJ prototype from the volunteers (normal and abnormal conditions) and observed that any of the used sensor data is high (here body temperature) and it is as per MEMW scored chart and it is a critical condition. The implemented system automatically communicated to the concerned people to be taken care of the patient's health.

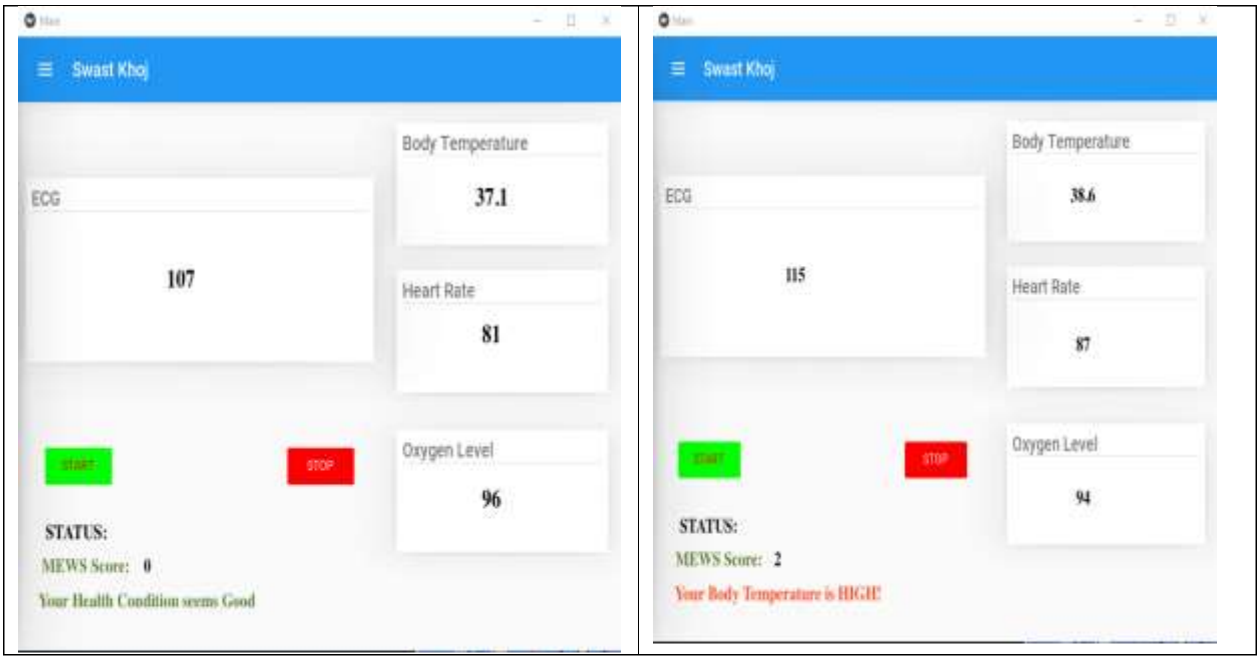

Figure 20: Normal and abnormal behaviour of GUI of prototype.

8. Performance Analysis

In this Section of our experiment, we have considered the following QoS parameter (like, End-to-End delay, average packet loss time and throughput) to establish our implemented working Prototype is more efficient compared to previously proposed prototype.

8.1. End-to-end Delay Matric

During our experiment, health data were collected from ten volunteers as shown in table 4. Each volunteer was monitored for 100 seconds with an interval of 2 ms. the health data of the volunteers has been stored in the local database shown in Figure 19. This process has been repeated for the different transmission media (Wired communication and Wireless communication). Every time end to end delay has been calculated using equation 1 [14].

$$T_d = \frac{1}{N}\sum_{k=0}^{N}(RT_k - ST_k) \quad (1)$$

Where, N is the number of successful transmissions, RT is the receiving time and ST is the sending time for the packet K. Figure 21 shows the average end to end delay for 100 transmissions for the different transmission media such as Ethernet is represented in blue colour, Wi-Fi is represent in Red colour, Zigbee is represent in Green colour and Bluetooth is represented in violet colour.

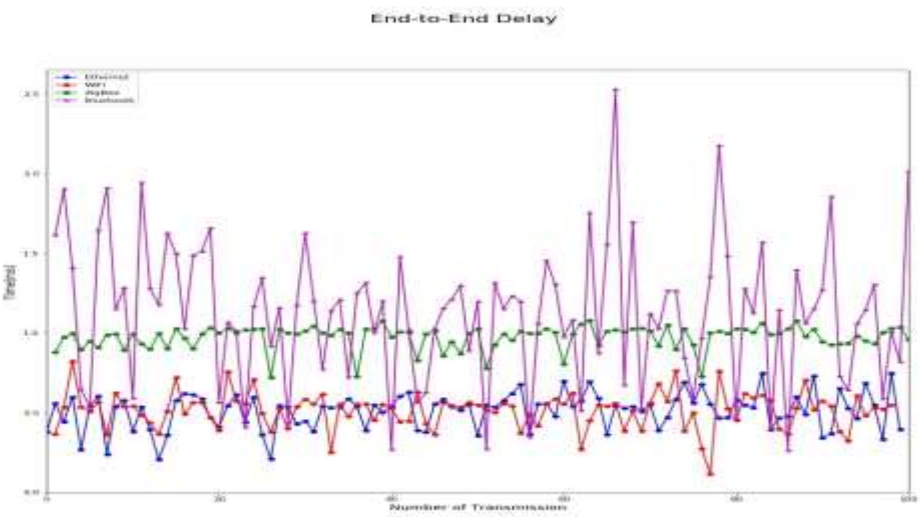

Figure 21: End-to-end delay of Ethernet, Wi-Fi, Zigbee and Bluetooth communication

Figure 21, shows that the number of transmission verse transmission time graph is plotted. Here, the Wired (Ethernet Cable) connection provides lesser End-to-End delay compared to other transmission media, whereas Bluetooth and Zigbee (being used as Serial bus) coincide with each other in the end to end delay graph. The average end-to-end delay of Ethernet cable , Wi-Fi, Zigbee, and Bluetooth is 0.514, 0.62, 0.977 and 1.92. Therefore, the Ethernet cable average delay is less compared to the other communication medium. The comparison of end-to-end delay with previous similar works has been represented in Table 7. The implemented SWAST KHOJ prototype is given better result.

Table 7: Comparison with other recent similar works

Author, Year	Number of Sensor Nodes	End-to-end delay(ms)
Saif et al. [14], 2022	03	2.71
Khan et al.[37], 2020	10	130
Murtaza and Ali [38],2020	80	70
Ullah et al. [39],2019	14	160
Proposed (SWAST KHOJ)	04	0.514

8.2. Average Packet Loss time Matric

It is defined as, one or more of these packets failing to reach its intended destination i.e. called packet loss. The average packet loss time is calculated by equation 2 [40].

$$Avg = \frac{1}{N}\sum_{K=1}^{N} x_k \quad (2)$$

Where N is the number of successful transmissions, and x is the lost time for packet k.

Here, consider ZigBee and Bluetooth is considered , Ethernet cable and WiFi is negligible because the distance of these is around to 150 meters or arbitrary in time (Seconds) and both in cases average loss time is very high, because data loss is minor. The serial data were recorded and observed for distances (meters) and it's range is considered from 0.25 meters to 2.0 meters.

Figure 22 shows Bluetooth in the red bar and Zigbee in the green bar average loss time and compares it with varying distances and observed that the average loss time of Bluetooth is more as compared to Zigbee. This indicated that the transfer rate of Zigbee is slower than Bluetooth but has a higher area coverage.

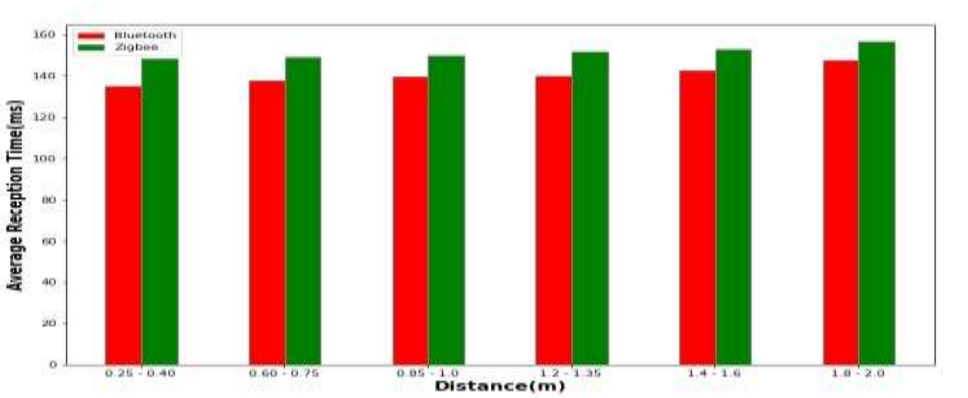

Figure 22: Average packet loss time matric Bluetooth and ZigBee.

8.3. Throughput

It is defined as the throughput is the amount of data moved successfully from the source node to the destination node in a given time, here considered time is 125ms (for medical application) [36]. The throughput of the different scenarios is shown in figure 23. It can be observed that the Throughput is highest for Ethernet Cable (here, used CAT 5e) because it is a point-to-point wire connection where the ends of the Ethernet Cable with RJ45 are connected to the involved devices directly, whereas throughput is lowest for Zigbee and Bluetooth because there no direct communication is involved. this means that for a specific amount of time, the highest amount of data can be sent reliably through a wired connection i.e. using Ethernet Cable, and for wireless connection: Wi-Fi proves to be more reliable compared to Zigbee and Bluetooth.

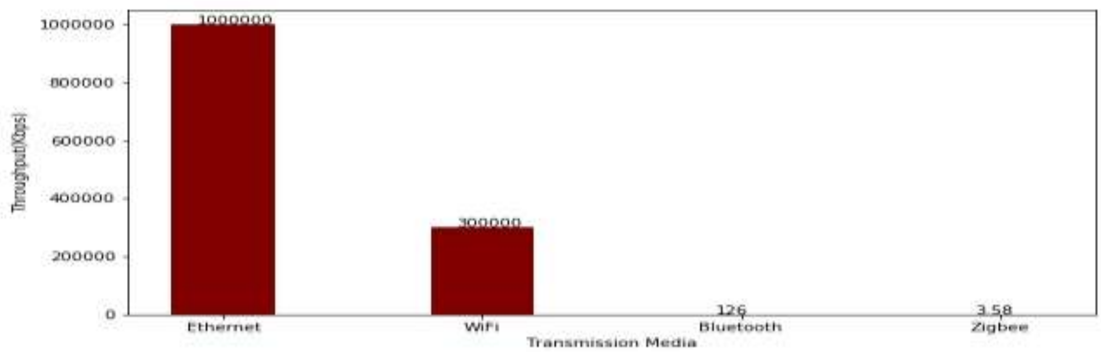

Figure 23: Throughput of Ethernet, Wi-Fi, ZigBee and Bluetooth Communications.

9. Conclusion

In implemented SWAST KHOJ prototype, we have focused on building a working prototype of a health monitoring system using different heterogeneous sensor nodes and devices in the indoor environment. The prototype works on real-time stamp and improvement of Quality of Service (QoS) parameters, which is compared with previous works and is found to be satisfactory. The GUI interface based case study shows the patient real time health condition as per MEMS medical guidelines and the collected data is stored in the medical server for future usage. The working prototype can also be useful for COVID 19 patient identification.

Future works might focus on the analysis and evaluation of different disease identification and health monitoring system. It is also planned to make a mobile prototype for both indoor as well as outdoor environments and integrate it with recent technology trends like AI, Machine learning and deep learning for IoT based healthcare systems.

Declarations

Ethical Approval

Not applicable

Competing interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

Authors' contributions

RS and SKB contributed to writing—the original draft, software and implementation of the prototype . SF and RG contributed to conceptualization, writing—review and editing. SS and SK contributed to the investigation and validation. All authors contributed to software, methodology and compile paper.

Funding

Not applicable

Availability of data and materials

All data included in this study are available upon request by contact with the corresponding author.

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