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Design and Implementation of IoT-Based Remote Vital Sign Monitoring System

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Research Article

Abstract:
The ability to save data on physiological parameters in a database has become more important in modern healthcare since it paves the way for analysis, enabling long-term patient monitoring, personalized medication, remote patient monitoring, and collaborative medical decision-making. This study presents the development of an online monitoring system that able to remotely monitor the patient at any time via web server. Using internet of things (IoT) technology, it is possible to develop an online patient monitoring system that read parameters, transmit data to database, store data, and display data. The system utilized the ESP32 microcontroller to collect physiological parameters through various sensors. The sensors for each parameter were selected: AD8232 was used for the Electrocardiogram (ECG), GY-MAX30100 was used for the Heart Rate and Blood Oxygen Saturation (SpO2), and MLX90614 was used for the body temperature. In addition, Google Firebase was adopted as the Web Server for this system, along with the implementation of statistical method. The accuracy test was then performed to check the accuracy of the reading. The physiological data were collected and monitored where the developed device was able to display the collected data in a connection with the database. The development of an online patient monitoring system using IoT technology enables remote monitoring, accurate data storage, and analysis of physiological parameters, leading to improved healthcare outcomes and reduced workload for medical professionals.

Keywords: IoT-based monitoring; Physiological data; Firebase integration; Remote monitoring

1. INTRODUCTION

The Patient Management System (PMS), also known as the Patient Administration System, is comprised of a collection of applications that are intended to enable service delivery managers and care providers to manage individual patients or groups of patients in a manner that is effective, flexible, adaptable, and customer-friendly while making the most of available resources. Consequently, a more appropriate moniker for it could be the customer Management System; having said that, the words described before have already attained widespread usage. The provision of services for taking care of the patient's health and disease is not included in this context as part of the definition of the term "management." The word "care" is used in this particular situation (1).

Patient monitoring systems that are currently implemented in Malaysia are done via physical monitoring which the doctor, nurse or medical assistant has to come and monitor the vital reading of the patient's physiological condition themself by attending the patient physically by each patient. This is a problem itself as there is a huge gap between the ratio of doctors and the population in Malaysia, especially those in rural areas (2). The doctor or nurse will have to monitor each patient by a person and it will take a lot of time for the procedure as there are more patients at a time especially at the more critical ward such as the Emergency Room and Intensive Care Unit (ICU). These issues are really worrying as it will affect our healthcare services and lose the trust for the patients as they will be risked with late treatment by the doctor or lack of monitoring by the doctor, nurse, or the medical assistance (2).

This vital sign monitoring system developed in order to assist the doctor or user to assess the patient's physiological condition simultaneously for all patients via internet connection based on a web server system which can be accessed remotely by the doctor or any user. This may help the doctor, nurse or medical assistant to monitor the patient anytime and anywhere as long as they have the access to the Healthcare System which enabled them to monitor the patient's physiological reading such as Electrocardiogram (ECG), Body Temperature, Blood Oxygen Saturation (SpO2) and Heart Rate. Even if there are too many patients at a time or lack of staff at a time, this Smart Healthcare Support Remote System may help to provide support to them by monitoring all the patients remotely by displaying the real-time data reading for all the patients (2).

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This Vital Sign Monitoring Remote System is a WIFI based system designed to assist the healthcare service by providing a remote monitoring system for the patients by using real-time data of the patients for assessing their physiological condition through a cloud web server called Firebase. The firebase server has its data from a microcontroller, ESP32 which control the hardware part like sensors that take the reading of physiological parameters like ECG, Body Temperature, Blood Oxygen Saturation and Heart rate and also processing it and control the transmission of data from the hardware to the web server and the cloud storage through internet connection. This microcontroller may be programmed via Arduino IDE for managing and transferring the data through the internet. The user may access it whenever or wherever they are as long as they have the access for the server system and stable internet connection (2).

The online server was designed at firebase as it is a server with a cloud database. The firebase stored in the cloud storage and display the physiological data either for the stored or the real-time data. The firebase also manages the online monitoring system for the user as they be able to access the real-time data reading of the patients as they can assess the reading for all the patients simultaneously.

2. METHODOLOGY

The Smart Health Care Support Remote System utilizes the three stage architectural features, which are Sensor Module, Data Processing Module and Web User Interface. The Sensor Module consists of ECG Sensor AD8232 and GY-MAX30100 pulse oximeter sensor. The Data Processing Module consists of ESP32 and the Web User Interface consists of Firebase Web Server, Database and User Interface. Figure 1 below shows the flowchart for the Vital Sign Monitoring Remote System.

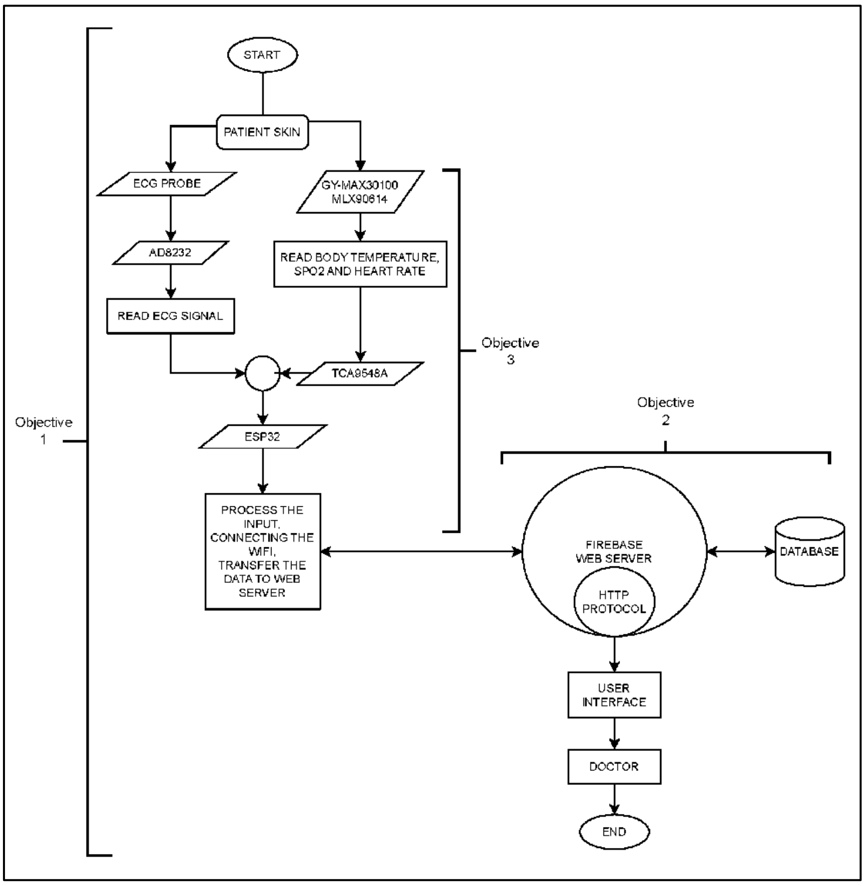

Figure 1. Flowchart of Smart Health Care Support Remote System.

In the beginning of the flowchart, the sensors are configured to collect input from the patient's body by gathering their physiological signs which are the ECG, SpO2, Heart Rate and Body Temperature. For the ECG parameter, three electrodes were placed on the patient's body and either in Standard Limb Leads, Augmented Unipolar Limb Leads and Unipolar Chest Leads positions (3). The electrode then collects the electrical signals of the heart activity as an input from the patient's body. The collected electrical signal then processed by AD8232 ECG sensor to get the targeted ECG waveform.

For the other parameters which are Heart Rate, SpO2 and Body Temperature, these parameters were collected by GY-MAX30100 Pulse Oximeter sensor and MLX90614. The GY-MAX30100 sensor release the red and infrared red light to capture the SpO2 reading, a green light to capture the Heart Rate reading while MLX90614 is a temperature sensor that use Infrared Light integrated with thermopile detector chip to collect the Body Temperature reading of the patients. All the three parameters collected and processed by the sensor and transfer its data to the microcontroller, ESP32. The collected input then processed via a microcontroller ESP32 module which connected to the internet via 2.4 GHz WIFI connection and transfer the processed data to the gateway server which is the Firebase cloud server via its built-in WIFI module.

For the Data Processing Module, the ESP32 programmed by Arduino IDE (Integrated Development Environment) by using Java Language. The ESP32 programmed to connect with WIFI and Firebase Web Server via its IP address, Project ID and Web API Key. The ESP32 also programmed to analyse the input data from GY-MAX30100 and AD8232 and transfer the processed data to Serial Monitor, OLED Display and the Firebase database. The path for the transferred data were also set in the program which is in the Firestore Database for storing the data in the cloud server and the Real-Time Database which is for displaying the data in real-time.

For the web user interface, they are mainly used for the graphical interpretation, and display of the collected data with the implementation of HTTP protocol that provides easy connectivity for the correspondence between a WIFI module and the web server. The Web Server consists of User ID for user purpose, Device ID which display the collected parameter data, the Firestore Database which display and keep the data and last but not least the Real-Time database which serves only for real-time display for monitoring purposes. The data received stored in the database and can be accessed via the web server through a User Interface for the user. The user may access it via an assigned User ID and monitor the patients simultaneously by checking on the Devices ID that assigned to the patients.

Once the device is operated, it measures the parameters and transfers its data to Firebase Database for displaying and storing purposes. The user must access it by their User ID to monitor the patients either by monitoring each patient's physiological parameter individually or by simultaneously monitoring every patient's physiological parameter. The user can then take action whether to pass the assessment or give any prescription to the patients due to their abnormal parameter or even attend the patients individually if the abnormal parameter is within a dangerous range of the parameter analysis.

2.1 Hardware Circuit Design

Figure 2 shows the schematic diagram of an IoT-based patient monitoring system. The system uses an ESP32 microcontroller as the central unit, connecting to multiple biomedical sensors. The AD8232 module measures ECG signals, the GY-MAX30100 sensor monitors heart rate and blood oxygen (SpO2) levels, and the MLX90614 sensor detects body temperature. A TCA9548A module is included for communication, while an OLED display is used to show real-time data readings. All sensors are properly interfaced using I2C and analog connections to ensure efficient data acquisition and transmission to the web server.

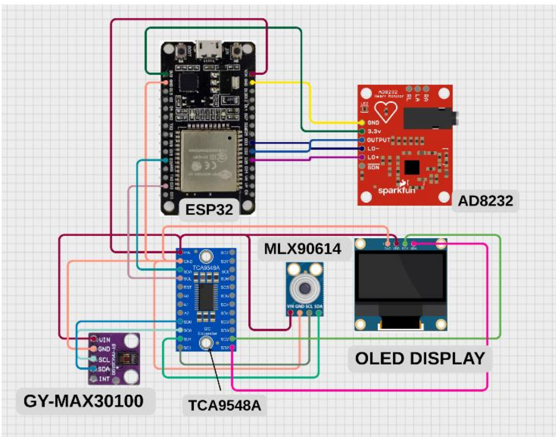

Figure 2. Schematic diagram of the circuit.

ESP32 is a strong SoC (System on Chip) microcontroller with integrated Wi-Fi 802.11 b/g/n which is only able to connect WIFI with 2.4GHz band, a dual Bluetooth version 4.2, 240 MHz clock frequency with 512KB RAM and able to function with various available peripherals like ADC(analog-to-digital converter), I2C(Inter Integrated Circuit), UART(Universal Asynchronous Receiver Transmitter), SPI(Serial Peripheral Interface), PWM(Pulse Width Modulation) and more due to it having General Purpose Input Output Pins(GPIOS) (4).

Several distinct models of the ESP32 microcontroller are currently in various stages of development. There are a wide variety of models available, some of which are the ESP32-DevKitC, the ESP32-DevKitM-1, the ESP-WROVER-KIT, the ESP32-PICOKIT, and the ESP32-PICO-V3-ZERO-DevKit. The applications, features, and circuit configurations that come with each of these models are one-of-a-kind and were developed just for that model (4). The ESP32-DevKitC was chosen to be utilized in this project as a result of the fact that it comes equipped with a development board that only has a select number of features and capabilities. It is not difficult to acquire access to any of the ESP32's pins, and the device's GPIO, UART, and I2C connections are all simple to set up and operate. They differ from conventional ESP32 boards in that they contain extra features that may be defined in the Arduino code. These features include an LCD display, a camera, an earphone jack, additional keys, and a variety of other options. This project, on the other hand, just required a microcontroller in order to integrate the circuit with the Firebase database through the use of a WIFI connection. As a result, these features are not applied to the project because they are not necessary for its completion.

A multiplexer, which also known as a "mux," is an electronic device that allows numerous input signals to be steered selectively to a single output. Based on control signals, it acts as a data selector, allowing one of several input lines to be transferred to the output line. Binary signals, digital logic, or microcontroller instructions can be used to control the input line selection. This project required a multiplexer to integrate multiple SCL/SDA pins for sensors connection as GY-MAX30100 and MLX90614 using the SCL/SDA pins (5).

In this project, TCA9548A has been selected to be used as multiplexer. There are others multiplexer that can be used in the circuit such as 74HC595, CD4051, 74HC151 etc. TCA9548A was selected since the multiplexer role in this project is to enable communication between multiple I2C devices by selected channels (5) while the other multiplexers use is for SPI devices, UART devices or for digital input-output pins on ESP32.

The TCA9548A multiplexer is a versatile component that allows for the connection of up to eight devices in a circuit, which can be controlled through an I2C bus. It acts as a bidirectional translating switch, enabling data communication between a master device and the selected slave device. By choosing the appropriate SCx/SDx channels, the multiplexer determines which device to read from or write to. One of the advantages of the TCA9548A is its compatibility with different voltage levels. It can operate at a low voltage of 1.8V, making it suitable for systems with lower voltage requirements. However, it can also handle a maximum voltage of 5V, providing flexibility for applications that operate at higher voltage levels. For the specific project mentioned, the multiplexer was configured to operate at an input voltage of 3.3V, which aligns with the system's requirements. This adaptability in voltage selection allows the multiplexer to integrate seamlessly into various electronic setups and meet the specific needs of different projects (5).

Overall, the TCA9548A multiplexer offers the capability to connect multiple devices, facilitates bidirectional data transfer, and operates across a range of voltage levels, making it a valuable component for managing complex I2C communications in electronic systems (5). The heart electrical signal was obtained through electrodes placed on the patient's body was measured and amplified by AD8232 sensor which utilize low power and noise reduction while able to directly transfer the signal to any controller such as Arduino Uno, Arduino Nano, Raspberry Pi or MS430 (6).

AD8232 is also a solid front-end for adaptation of cardiac biopotential signals and for heart rate monitoring. It contains a certain instrumentation amplifier, a right leg drive amplifier, operation amplifier and intermediate supply reference buffer. The AD8232 comprises a lead off recognition circuit and an automatic fast reinstate circuit that recovers the signals after reconnecting the leads. The AD8232 contains a particular instrumentation amplifier which amplify the ECG signal while rejecting the latent half-cell of the electrodes at the same phase. This indirectly presents that the response architecture can be accomplished with the minimum size and power compared to traditional execution.

The GY-MAX30100 is an integrated heart rate monitor and pulse oximeter sensor module that can find the heart rate signals, pulse count and temperature (7). It has two LEDs which are a red LED (660nm) and an infrared LED (860nm) which then produce two different wavelengths of light, a photodetector for engaging the two different wavelengths, a Specialized Optics, a low-noise analogue signal processing unit to process the signals before transferred to targeted controller. The GY-MAX30100 is able to operate in two voltages which are 1.8V and 3.3V which are managed by the built-in voltage regulator (7). The MLX90614 is an infrared thermometer for measuring temperature without contact. In the same TO-39 package are both the IR-sensitive thermopile detector chip and the signal conditioning ASSP. The thermometer’s high precision and resolution are made possible by its low-noise amplifier, 17-bit ADC, and potent DSP unit. The MLX90614 is factory calibrated in wide temperature range which is 70°C to 380°C for the object temperature while -40°C to 125°C for the ambient temperature (8).

There are also several types of temperature sensor like Thermistor, LM35, DHT11, TMP36 and many more. The MLX90614 was selected since it makes use of infrared sensing technology so that it is not necessary to physically touch an object in order to obtain its temperature. It is able to measure the temperature of objects in a non-intrusive manner, which makes it useful for applications in which direct contact temperature monitoring is either not possible or not desired. Also, The MLX90614 combines two sensors into a single unit which are for ambient temperature and object temperature. By accounting for the ambient temperature, this dual-sensor arrangement gives more precise temperature measurements (8).

An organic light-emitting diode, sometimes known as an OLED display, is a type of display technology that employs the utilization of organic compounds to produce light in response to the application of an electric current. OLED displays are renowned for their excellent contrast, wide viewing angles, lightning-fast reaction speeds, and small overall profiles. OLED displays can either have a passive matrix or an active matrix depending on the application. The individual pixels in passive-matrix OLEDs, also known as PMOLEDs, are controlled by a straightforward matrix consisting of rows and columns. AMOLEDs, or active-matrix organic light-emitting diodes, are organic light-emitting diodes that use thin-film transistor (TFT) technology to control each pixel independently (9). This allows for improved image quality as well as higher refresh rates. Figure 8 shows the image of an OLED Display.

With the current configuration utilizing only three sensors, one OLED display, and a single multiplexer, the overall cabling requirements have been significantly reduced. As a result, the circuit now features a more streamlined and focused set of core hardware connections. Specifically, the OLED display is connected to channel 1 of the TCA9548A multiplexer, while the MLX90614 and GY-MAX30100 sensors are connected to channels 0 and 6, respectively. The desired output, which is the numerical value of each physiological parameter, can be displayed on the OLED display even as the ESP32 is simultaneously uploading the same data to Firebase Database. This is the case because the OLED display uses a different type of backlighting. This takes place at the same time that the ESP32 is concurrently posting the same data.

Previous studies projects mostly using Arduino Uno (10-12), Arduino Pro Mini (6) and Arduino Mega 2560 (8) as microcontroller with external WIFI module for connecting with internet. Vital Sign Monitoring Remote System used Esp32 which is a microcontroller that has built-in WIFI module. This greatly reduce the wiring complexity as there are no needs on additional wiring for external module except for multiplexer since it was applied to connect the digital sensors. For displaying the output, all the studies only use one display output either on software like Blynk (12-13) or User Interface (5) or trough hardware screen integrated on the circuit such as LCD screen (3) or Liquid Crystal Screen (10). The Vital Sign Remote Monitoring System using both software and hardware screen to display its output which is Realtime Database to display and monitor the data on cloud server and OLED screen for monitoring the vital signs physically which greatly increase the projects functionality as the user able to monitor the vital signs either in-site or remotely.

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The most common sensor being used through the studies is GY-MAX30100 which use for either taking reading on heart rate or SpO2 (3, 10, 12, 13) while for ECG parameter, the sensor used to take the reading of ECG is AD8232 (11). Most studies used one or two sensors to measure the physiology parameters (3,11,12,13) but only Hasan & Ismaeel (10) used different sensors for each physiological parameter as they were monitoring 5 parameters indicates that they were using 5 different sensors which cause the circuit becoming more complex (10). Vital Sign Monitoring Remote System used 3 sensors to monitor the 4 physiological parameters. Two of the sensors which are MLX90614 and GY-MAX30100 were connected using multiplexer as both sensors were a digital sensor and ESP32 don't have enough pin for digital sensors while the other one which is AD8232 sensors is an analog sensor, thus it was connected with other GPIO pin. These has greatly reduced the circuit complexity while providing optimal function for monitoring purposes.

2.2 Web Server Database

Firebase is a blend of several Google's services in the cloud, like instant messaging, user authentication, real-time database, data storage, server hosting, and many more. This project mostly applies its user authentication, Firestore database and real-time database functions. The Firebase cloud system offers data transmission with SSL encryption and data transmission. Firebase platform offers a cloud-hosted database system called the Realtime Database which follows the NoSQL mechanism which is less complicated but less structured than the normal database. This enables for the real-time storage of large datasets which integrated to all the connected clients inside the database's access. Firebase released a new database called Firestore, the Realtime Database was chosen as a result of its lower latency, which improve the real-time implementation of data visualization (12). Security might be one of the most difficult aspects of app development. Most apps require developers to create and maintain a server that handles authentication (who a user is) and authorization (what a user can do). Firebase Security Rules eliminate the intermediate (server) layer, allowing you to establish path-based permissions for clients who connect directly to your data (12). Also, by utilizing many ways, such as email/password, social logins, and more, user can quickly authenticate users utilizing Firebase's built-in authentication services. Additionally, it provides strong security guidelines to restrict access to your data and protect your privacy (12).

2.3 Data Collection

For data collection, a total of 10 subjects participated in the study and received readings of their ECG, heart rate, oxygen saturation, and body temperature from both the sensors and the real device. The primary objective of this study was to evaluate the accuracy of the readings obtained. The analysis of the ECG parameter involved examining the graphical representation of the ECG waveform captured by both the AD8232 sensor and the ECG machine PHILIPS Page Writer TC70. For all other physiological parameters, data collection was conducted three times for each subject, and the average values were calculated. However, for the ECG parameter, the average data was computed based on the captured waveforms. To assess the accuracy of heart rate and oxygen saturation level measurements, the reading data obtained from the GY-MAX30100 sensors was compared with the readings from the Pulse Oximeter model SMH-01. This comparison aimed to determine the consistency and reliability of the sensor-based measurements in relation to the established device. Similarly, the reading data obtained from the MLX90614 sensor was compared with the readings from the Nex model K3 to evaluate the accuracy of the body temperature measurements. By conducting these comparative analyses and calculating average data, the study aimed to assess the reliability and accuracy of the sensor-based readings in capturing the physiological parameters of the subjects.

The actual devices used in the testing phase included the Pulse Oximeter SMH-01, the PHILIPS Page Writer TC70 ECG machine, and the Thermometer K3. The Pulse Oximeter SMH-01 and the Nex model K3 are portable pulse oximeters that conform to the standard requirement of electromagnetic compatibility specified in IEC60601-1-2 (14–15). These devices have been designed and manufactured to meet the necessary standards to ensure their reliable and accurate performance in measuring oxygen saturation and pulse rate. On the other hand, the ECG machine PHILIPS Page Writer TC70 demonstrates compliance with the standards outlined in IEC 60601-1, which pertains to the safety and performance of medical electrical equipment. Additionally, it adheres to the safety requirements for electrocardiographs specified in IEC 60601-2-25. These standards ensure that the ECG machine meets the necessary safety regulations and performs reliably and accurately in capturing and analysing the electrical activity of the heart.

It is important to note that all the actual devices used in the testing phase comply with the relevant standards and regulations in the field of medical devices. This compliance ensures that the devices are safe to use and provide accurate measurements of the physiological parameters being assessed. By utilizing these compliant devices, the study ensures the reliability and validity of the obtained data for the evaluation of the sensor-based readings. During the ECG data collection process, the subjects were positioned in a comfortable sitting position, and the ECG electrodes were carefully applied to their skin as shown in Figure 3. The Standard Limb Leads configuration was utilized for both the PHILIPS Page Writer TC70 ECG machine and the AD8232 ECG Sensor. To record the ECG data from the AD8232 sensor, a third-party software, CoolTerm was employed, which allowed for the recording of the data in the form of a CSV file. The collected data was subsequently imported into MATLAB for further analysis and interpretation.

During the heart rate and SpO2 data collection procedure, the subjects were positioned in a relaxed seated position and instructed to wear both the SMH-01 pulse oximeter and GY-MAX30100 sensor simultaneously on different hands, as the purpose was to obtain accurate readings of their heart rate and oxygen saturation levels. The data collection process consisted of three separate sessions for each parameter, with a time gap of approximately 5 minutes between sessions. This allowed for adequate rest and recovery between readings, ensuring that the subject's physiological state was stable before proceeding with the next measurement. The recorded data from the sensors provided valuable insights into the subjects' cardiovascular health and oxygenation levels.

Figure 3. Subject position for ECG data collection.

For the temperature reading test, the subjects were asked to measure their body temperature using the thermometer K3 and MLX90614 sensor. Similar to the heart rate and oxygen saturation measurements, the temperature readings were taken in three separate sessions, with a time gap of 5 minutes between each session. This allowed for consistent intervals and ensured that the subject's body temperature had remained stable between readings. In both cases, the readings were recorded and stored for further analysis. To obtain reliable and accurate results, the average value of each parameter for each subject was calculated based on the multiple readings taken from both the sensors and the actual devices. This approach aimed to reduce any potential measurement errors or variations and provide a more representative value for each parameter.

To investigate the extent to which the readings received from the sensors and those obtained directly from the devices themselves are similar with one another, a statistical study based on the T-test was carried out in order to compare the two sets of data. The T-test made it possible to compare the means of the two different sets of readings, which helped shed light on the extent to which the two sets of data agree or disagree with one another. To evaluate the accuracy and reliability of the readings received from the sensor-based devices in comparison to the readings obtained from the actual devices, with the exception of the ECG reading, the purpose of the study was to follow this systematic testing approach and perform the appropriate statistical analysis. The ECG reading was the one reading that was excluded from this comparison. The reading from the electrocardiogram (ECG) was analysed based on each characteristic of the ECG, such as the interval, segment, and amplitude, all of which are discussed in further depth in the result and discussion.

3. RESULT AND DICUSSION

3.1 Firebase: Real-Time Database

For the real-time database, the device assigned with an ID under the unit called SensorData. For example, from Figure 4, an ID named Luqmanaz was assigned to the device and four parameters were to display under its ID. The four parameters are ECG, Heart rate, SpO2 and Body Temperature. The parameter real-time data was read and displayed in the real-time database by each respective parameter. The path for the ESP 32 to update the data through the real-time database is provided by the API-Key provided in the Firebase.

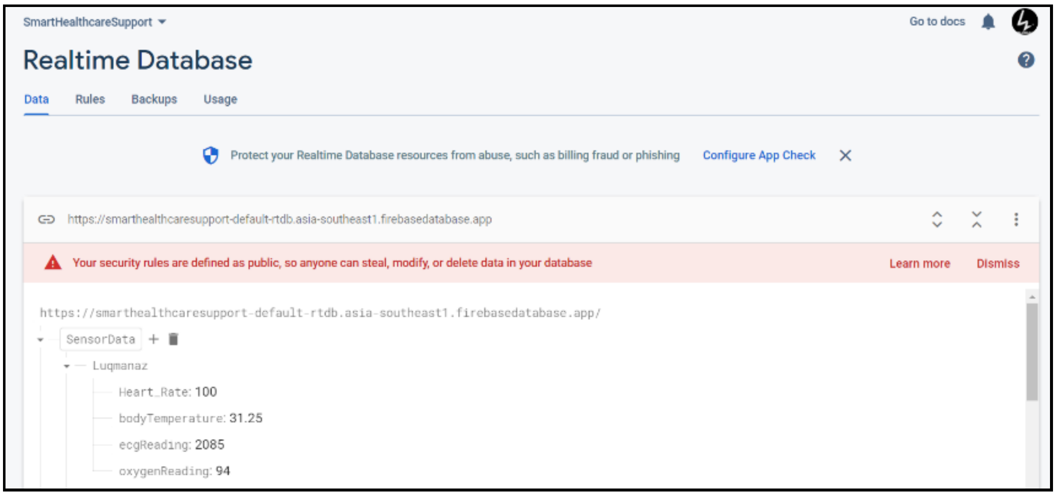

Figure 4. Firebase real-time database.

3.2 Firebase: Firestore Database

In the cloud Firestore implementation, the device is assigned a unique ID within the unit SensorData, as depicted in Figure 5. Similar to the real-time database, it utilizes the same parameters for storing readings. However, Firestore introduces an additional functionality in the form of a timestamp, which records the exact time and date when the parameter reading is taken. This timestamp feature allows for precise tracking and analysis of the data over time. Furthermore, the Firestore database extends its capabilities beyond parameter readings. It includes storage for doctor-related information, such as their specialty and affiliated hospital, as shown in Figure 5. This enables efficient organization and retrieval of doctor-specific data within the system.

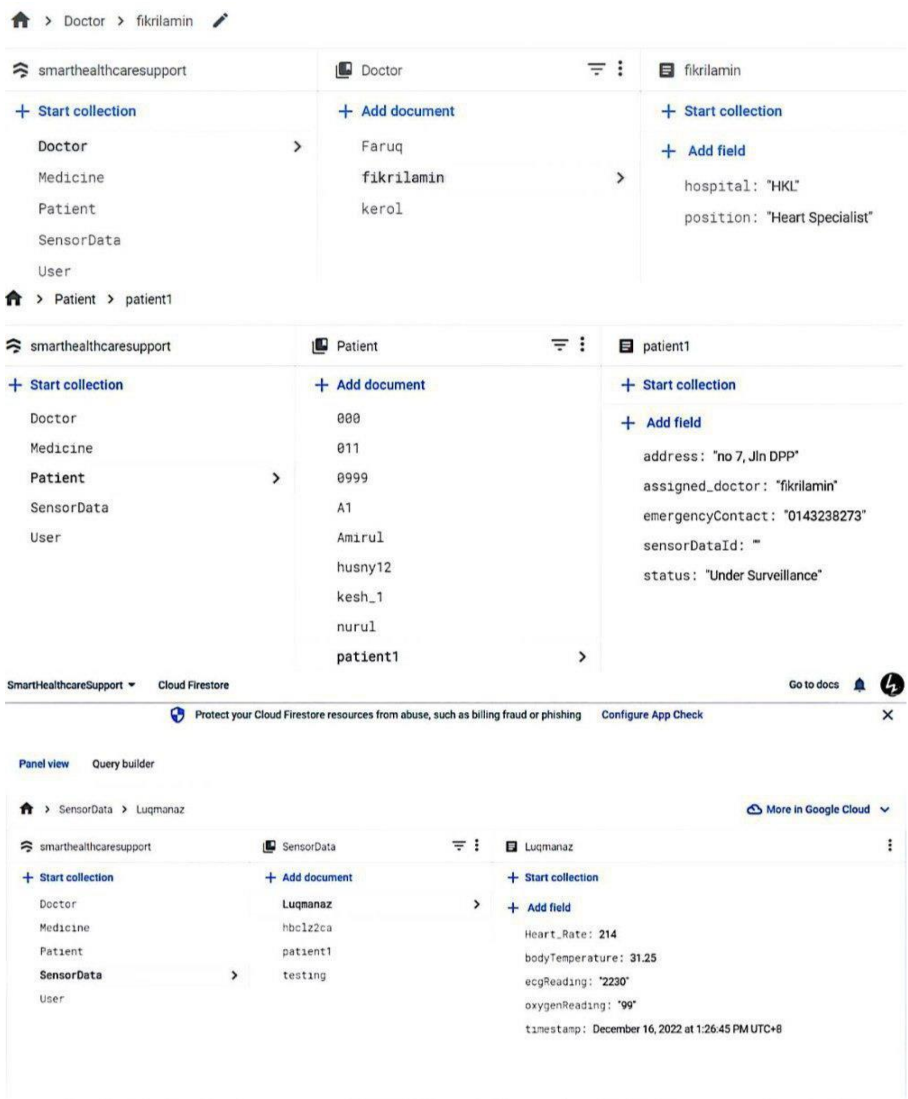

Figure 5. Firebase Firestore database.

Additionally, the database accommodates patient data, which includes an assigned ID for the device, status information, emergency contact numbers, and assigned healthcare professionals, as illustrated in Figure 5. This comprehensive approach ensures that both patient and doctor data are securely stored and easily accessible within the Firestore database structure. There was also other system in which monitoring the physiological parameters but only to certain parameters such as in Hasan & Ismaeel (10), an online monitoring system was designed using Blynk with mainly focused only on ECG parameter (10). The project reading the ECG data and store it in Blynk database while being display for monitoring purposes also in Blynk application. Other projects have proposed a system for monitoring vital sign for Heart Rate, SpO2 and Body temperature but with different system for the device like GSM (Global System for Mobile Communications) and ThingSpeak which proposed by Tamilselvi *et al.* (17), Zigbee Technology and star topology by Banuag & Salva (11), Blynk application by Jayanthi *et al.* (13), and last but not least Thinger.io by Luthfiyah *et al.* (12).

The vital sign parameter could be monitored by all project systems, but only projects that used the Blynk system which were used by Hasan & Ismaeel (10) and Jayanthi *et al.* (13), were able to save the data. The data can be stored in Blynk for monitoring purposes, and the results can be displayed through the Blynk application. Google's Firebase server, which is a cloud server that was built by Google, was also used to collect and store the data on the vital signs that were taken. The Vital Sign Remote Monitoring System utilized this Firestore database in order to accomplish the objective on designing an online Vital Sign Monitoring System that is able to assist on monitoring the patient's physiological condition. In contrast to Blynk, this server has the ability to be integrated with the program or application of a third party.

Furthermore, in order to enhance user experience and functionality, there is a possibility to develop a new software interface that can seamlessly integrate with the Firebase server. This software can provide a user-friendly interface for accessing and analysing the data stored in the Firestore database, which includes vital sign readings, patient identification, prescriptions, and other relevant information. By leveraging this software, the project can be further improved with additional features and enhancements, allowing for more efficient and effective management of patient data and healthcare processes. Moreover, the new software interface can offer advanced data visualization tools, allowing healthcare professionals to easily interpret and analyse the collected data. It can also provide real-time monitoring capabilities, enabling remote access to patient information and facilitating timely interventions when necessary. By continuously working on the project's improvement, the software can contribute to the overall enhancement of patient care and vital sign monitoring system while solving the issues with user interface with existing application or software.

3.3 Accuracy Test

For accuracy test, for Heart rate and oxygen saturation, the subjects sat on a chair while wearing the SMH-01 pulse oximeter and GY-MAX30100. Three sessions for the parameter reading were taken with time gap for each session is around 5 minutes. For temperature reading test, the subjects began measuring their body temperature using thermometer K3 and then MLX90614. The readings were also taken once every 5 minutes with a total of three readings for both MLX90614 and thermometer K3 were taken. From all the reading, an average value of each subject from sensors and actual devices were taken and perform T-test.

While for the ECG analysis, the results from the ECG graph paper generated by the ECG machine PHILIPS Page Writer TC70 of the ten subjects were manually analysed by calculating the boxes for the parameters in the ECG graph as each one small box indicates 4ms for time on x-axis and 0.1 mV for amplitude on y-axis. These parameters include the PR-Interval, QRS-Interval, ST-Interval, PR-Segment, ST-Interval, P peak, R peak, and S peak for the ECG graph. Because the reading from the AD8232 sensors is in numerical form and needs to be displayed using a plotter, the ECG graph was extracted and recorded using CoolTerm and analysed using MATLAB. This was done because the reading from the AD8232 sensors needs to be plotted. After carrying out the analysis, all of the parameters for the ECG graph were compared, and the percentage of error was computed based on the differences between each parameter.

As shown in Table 1 to 3, the project took the average of the readings that each subject received from both the sensors and the actual device in order to calculate the subjects' heart rates, oxygen saturations, and body temperatures, respectively. After that, the average values utilised in the computation of the percentage of error as well as the T-test for the subsequent analysis which later use for data validation for the sensors reading.

Table 1. Reading data taken on Heart Rate parameter from pulse oximeter and GY-MAX30100

Subject	Average (Oximeter)	Average (GY-MAX30100)	Difference	Percentage of Error
N1	84.67	85.67	1.00	1.20%
N2	82.67	79.00	3.67	4.17%
N3	74.67	75.67	1.00	1.37%
N4	66.33	76.33	10.00	16.39%
N5	76.33	68.33	8.00	9.64%
N6	74.67	73.33	1.33	1.52%
N7	79.67	82.33	2.67	3.51%
N8	74.00	80.33	6.33	8.92%
N9	75.33	75.33	0.00	0.00%
N10	72.00	74.67	2.67	3.92%

Table 2. Reading data taken on Oxygen Saturation from pulse oximeter and GY-MAX30100

Subject	Average (Oximeter)	Average (GY-MAX30100)	Difference	Percentage of Error
N1	97.67	98.33	0.67	0.68%
N2	98.67	97.67	1.00	1.01%
N3	97.33	97.67	0.33	0.33%
N4	97.00	98.67	1.67	1.74%
N5	97.67	99.33	1.67	1.70%
N6	96.00	100.00	4.00	4.17%
N7	97.00	96.67	0.33	0.33%
N8	96.00	93.67	2.33	2.46%
N9	97.33	99.00	1.67	1.70%
N10	94.00	94.33	0.33	0.35%

From all the reading of the subjects in Table 4, a T-test to find the P-value was performed in spreadsheet by using its function for T-test, with hypothesis as below:

Null Hypothesis:
H0 – No significance difference between actual device and sensors.
Alternative Hypothesis:
H1 – There is significance difference between actual device and sensors.

Table 3. Reading data taken on Body temperature from thermometer K3 and MLX90614

Subject	Average (Thermometer K3)	Average (MLX90614)	Difference	Percentage of Error
N1	36.367	36.543	0.177	0.49%
N2	35.967	35.430	0.537	1.50%
N3	36.533	36.623	0.090	0.25%
N4	36.500	36.437	0.063	0.17%
N5	36.133	36.237	0.103	0.29%
N6	36.400	36.310	0.090	0.25%
N7	36.300	36.357	0.057	0.16%
N8	36.433	36.530	0.097	0.27%
N9	36.300	36.130	0.170	0.47%
N10	36.367	36.523	0.157	0.43%

The analysis was discussed in detail for each physiological parameter. The P-value obtained from Table 5 show that the T-test for the heart rate parameter is 0.5168. Because the P-value is greater than 0.05, the T-test for the Heart Rate parameter fails to reject the null hypothesis, indicating that there are no significant differences in heart reading measurements acquired from the GY-MAX30100 with the SMH-01 Pulse Oximeter. This demonstrates that the measurement has no significant differences with the actual device, while the Average Percentage Error is calculated at 6.85%, indicating that there is a possibility of measuring the Heart Rate parameter incorrectly due to the large range of data, which is 6.85% of the reading data. According to (18), heart rate monitors must precisely identify the QRS complex and measure heart rate within a given margin of error. A percentage of the reference heart rate or a certain number of beats per minute (bpm) are two common ways to set this error limit. Depending on the situation and intended application, the precise permissible error rate may change, but a frequently mentioned standard is an accuracy of no more than 5% or ±10 bpm, whichever is higher (18). Because the GY-MAX30100 sensor has a specified range value of 6.85% for heart rate measurements, and the allowable range given in the standard is 5%, the reading obtained from the GY-MAX30100 as in Table 1 does not exceed the reading range of ±10 bpm, then the reading from GY-MAX30100 sensors still accepted.

Table 4. Reading data taken on ECG from PHILIPS Page Writer TC70 and AD8232.

Subject	Type Parameter	Interval (s)			Segment (s)		Amplitude (mV)		
		PR Interval	QRS Interval	ST Interval	PR Segment	ST Segment	P	R	T
N1	Actual	0.12	0.08	0.28	0.04	0.08	0.30	1.50	0.20
	Experimental	0.18	0.06	0.28	0.05	0.09	0.24	1.30	0.21
N2	Actual	0.20	0.08	0.28	0.08	0.04	0.2	1.3	0.3
	Experimental	0.18	0.05	0.30	0.06	0.05	0.19	1.60	0.43
N3	Actual	0.08	0.08	0.28	0.08	0.08	0.10	2.00	0.30
	Experimental	0.09	0.10	0.23	0.04	0.10	0.29	1.64	0.32
N4	Actual	0.12	0.04	0.32	0.08	0.08	0.10	1.50	0.30
	Experimental	0.12	0.07	0.27	0.07	0.06	0.10	1.50	0.29
N5	Actual	0.16	0.04	0.28	0.04	0.08	0.20	1.60	0.30
	Experimental	0.18	0.03	0.26	0.06	0.08	0.24	1.59	0.31
N6	Actual	0.16	0.04	0.32	0.04	0.12	0.30	1.30	0.30
	Experimental	0.21	0.05	0.32	0.06	0.12	0.30	1.00	0.30
N7	Actual	0.20	0.04	0.28	0.08	0.12	0.20	1.70	0.10
	Experimental	0.20	0.06	0.25	0.10	0.10	0.18	1.70	0.14
N8	Actual	0.16	0.04	0.24	0.08	0.08	0.20	1.40	0.10
	Experimental	0.20	0.05	0.24	0.06	0.10	0.19	1.40	0.15
N9	Actual	0.16	0.04	0.28	0.08	0.08	0.10	0.60	0.30
	Experimental	0.15	0.05	0.26	0.07	0.05	0.11	0.70	0.48
N10	Actual	0.16	0.04	0.24	0.08	0.08	0.10	0.60	0.20
	Experimental	0.12	0.04	0.24	0.11	0.11	0.22	0.57	0.32
Average	TC70 ECG	0.152	0.052	0.280	0.068	0.084	0.18	1.350	0.240
	AD8232	0.163	0.056	0.265	0.131	0.086	0.206	1.30	0.295
	Difference	0.011	0.004	0.015	0.063	0.002	0.026	0.05	0.055
	Percentage	1.1	0.4	1.5	6.3	0.2	2.6	5	5.5

Table 5. T-test result (P-Value) and average percentage error of data from actual devices and experimental data from sensors.

Parameter	T-Test (P-Value)	Average Percentage of Error (%)	Accuracy (%)
Heart Rate	0.5168	6.85	93.15
Oxygen Saturation	0.2549	2.35	97.65
Temperature	0.6566	0.64	99.36

The T-test P-value was 0.2549, which is greater than 0.05. This demonstrates that this project was unable to rule out the null hypothesis for the oxygen saturation parameter and that the oxygen saturation readings from the GY-MAX30100 and SMH-01 pulse oximeters do not differ significantly. According to the average error percentage of 2.35%, the oxygen saturation sensor has a minor error. This also demonstrates that the reading results from the GY-MAX30100 sensor are accurate within 97.65%. For SpO2 measurements in the 70% to 100% range, the International Organisation for Standardisation (ISO) 80601-2-61 standard recommends that pulse oximeters have an expressed accuracy of 2% or 1 digit, whichever is greater. Since the accuracy of the SpO2 reading is 97.65%, and the reading accuracy range is within ±2.35% (19). Thus, the SpO2 reading as in Table 2 was accepted since the reading still fall under the standardized range.

The P-value for body temperature derived from the T-test is 0.6566, which is greater than 0.05 which indicates that the analysis did not reject the null hypothesis, implying that there is no significant difference between the Temperature Sensor MLX90614 and the Thermometer K3. The average percentage of error for body temperature is 0.64%, which is quite low among physiological parameters. This shows that the MLX90614 has a low percentage of error with 0.64% for the reading, and the MLX90614 has a high accuracy 99.34% which are higher accuracy when compared to the other sensor. This has shown that the temperature reading from MLX90614 has range value of ±0.64% of the reading. The accuracy required for body thermometers, as stated in the International Electrotechnical Commission (IEC) 80601-2-56 standard, is normally ±0.2°C for a measurement range of 35°C to 42°C (20). Since all the reading from MLX90614 as in Table 3 has difference within the standards range, then the body temperature reading is acceptable.

Table 6. Percentage of error on ECG parameters between AD8232 with actual ECG device.

Types	Parameter	Percentage Error (%)	Accuracy (%)
Interval (s)	PR Interval	1.1	98.9
	QRS Interval	0.4	99.6
	ST Interval	1.5	98.5
Segment (s)	PR Segment	6.3	93.7
	ST Segment	0.2	99.8
Amplitude (mV)	P	2.6	97.4
	R	5	95.0
	S	5.5	94.5

For the purpose of ECG analysis, the average % error for each of the ECG parameters was calculated using the AD8232 and the ECG device. Based on the information presented in Table 6, this project can deduce that there are two ECG parameters that are greater than 5%. These parameters are PR Segment and S Wave, and their respective values are 6.3% and 5.5%. The value of the R peak parameter is precisely 5%. Other ECG characteristics, such as the PR interval, are below 5%, including the QRS interval, which is 0.4%, the ST interval, which is 1.5%, the ST segment, which is 0.2%, and the P wave, which is 2.6%. Three of the ECG values have already reached and above 5%, whereas the remaining parameters have not yet achieved this threshold. This may have occurred as a result of the AD8232 data processing since the built-in filter may not have been efficient enough to remove the majority of the filter. The ANSI/AAMI EC13:2002 standard specifies that the acceptable QRS complex, PR Interval, ST Interval and ST segment detection error should generally be less than 10%, while others which are PR segment, P wave and S wave should be less than 5% (19). But, since the S wave and PR Segments exceed the 5%, thus the ECG reading was not accepted.

4. CONCLUSION

In conclusion, a Vital Sign Remote System was conceived of and developed. It integrated the hardware and software components of the system, such as the microcontroller, sensors, and database, in order to make use of the Internet of Things technology. An online patient monitoring system that is capable of reading the parameter, transferring the data to the database, storing the data, and displaying the data may be built with the use of the Internet of Things technology that was implemented in the system. In addition, the parameter measurements of the sensors were tested by way of a comparison with the actual equipment. The purpose of this comparison was to determine whether or not there was a significant difference between the readings obtained from the actual device and the Sensors. A measurement was also taken of the percentage of error. Since the device is able to offer physiological parameters of patients in a distant setting, this device undoubtedly be of significant use to the healthcare service industry. As a result, the workload of the nurses reduced, and it also provide flexibility because it can be accessed remotely and at any time, all while the device system continue to monitor the patient continually.

AUTHORSHIP CONTRIBUTION STATEMENT

Muhammad Nor Luqman: methodology, experimental work, formal analysis, investigation, conceptualization, writing – original draft; Mohd Riduan Mohamad: supervision, methodology, resources, writing – review & editing, validation, funding.

DATA AVAILABILITY

Data supporting this study’s findings are available upon reasonable request from the corresponding author.

DECLARATION OF COMPETING INTEREST

The authors have no conflict of interest.

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