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Design and Clinical Validation of an IoT-Enabled Multiparameter Vital Sign Monitoring System

Maulesh H Parikh[1], Khushi Shah[2], Dr. Abhinam H Patel[3], Anurag Patel freelancing[4]

[1]Email: maulesh.parikh23175@paruluniversity.ac.in
[2]Jr. Software Engineer Garima System Solutions Pvt. Ltd. Khushi210104@gmail.com
[3]M.D Internal Medicine Associate Professor Department of Medicine, PIMSR
abhinam.patel36241@paruluniversity.ac.in
[4]Email: anuragpt@gmail.com

ABSTRACT

Continuous real-time monitoring of vital signs is important in early disease detection. Conventional healthcare systems usually employ periodic check-ups and manual reporting. The rapid evolution of the Internet of Things (IoT) has revolutionized ailment detection and diagnosis in healthcare. This paper provides an IoT-primarily based device intended for actual-time tracking of significant signs. The gadget utilizes varied biomedical sensors to capture essential physiological parameters, including body temperature, arterial oxygen saturation, systolic and diastolic blood pressure, and coronary heart rate. The parameters are important in determining and diagnosing illness. The gadget in question uses a centralized cloud platform to aggregate the gathered data, allowing real-time processing and scientific analysis. Also, it features an active alert device that informs doctors immediately when it detects any abnormal readings or when values surpass normal limits, considering triggered scientific intervention. The main purpose of this device is to enable healthcare professionals to show affected person health remotely, in particular in scenarios where in-person consultations are inconvenient. Major characteristics of the device include real-time visualization of information, consistent user authentication, and a clean-to-use records export feature for patient fitness records. The readings produced through this device have proven reasonable accuracy and reliability in measuring crucial signs and symptoms. In addition, the suggested machine enhances affected person care by allowing timely interventions thru constant records acquisition and analysis.

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1. Introduction

The use of IoT for real-time monitoring and management of data has created new avenues for healthcare. Moreover, the growing requirement for efficient and cost-effective healthcare solutions for chronic diseases necessitates the development of innovative real-time systems for patient health monitoring [1, 2]. The vital signs such as heart rate, blood pressure, breathing rate, and body temperature, which are obligatory parameters for diagnosing any illness and medical ailments [3, 4]. In addition, ongoing monitoring of vital signs is an essential instrument for doctors, which represents the human physiological status and helps improve patient care [5, 6].

The traditional methods for capturing vital signs are data capturing by patient interaction, which limits accessibility, mostly in rural and remote areas [7]. Also, the invariability of the manual recording of vital signs by doctors in different clinical settings impacts the

process of decision-making and diagnosis [8]. Therefore, there is a need for a healthcare system that is able to automate gathering and transmission of vital sign data for early intervention and better management of health data [9, 10]. Therefore, this research aims to enhance patient care, promote clinical outcomes, and change the face of contemporary healthcare delivery using IoT devices with improved analytical capabilities [11].

This paper presents a multi-parameter IoT system designed to monitor vital signs for human health monitoring. It integrates some biomedical sensors with a microcontroller to capture and transfer data into an internet application in real time [12, 13, 14]. The system suggested captures four critical parameters of the human body. Then, the data captured is transferred to a web application for diagnosis and analysis in case of any disease [15, 16]. Furthermore, the proposed system also enables doctors to interact with patients through a simple interface, with options for saving,

analysing, and exporting patient records as required [17, 18]. The system reengineers traditional methods of vital sign monitoring by employing IoT with data visualization [19, 20].

1 Proposed IoT- based System for Vital Sign Assessment

The system presented in Fig. 1 is composed of several components combined into a breadboard for flexible and modular design. A NodeMCU ESP32 microcontroller, a MAX30102 pulse oximeter sensor, a Dallas temperature sensor DS18B20, a Raspberry Pi, and a 3D display screen are interfaced through the breadboard. The sensors capture vital parameters such as heart rate, SpO_2 levels, and body temperature. The Raspberry Pi acts as a processing and display unit, receiving data from the ESP32 and rendering it visually on the 3D screen, enhancing real-time monitoring and analysis capabilities.

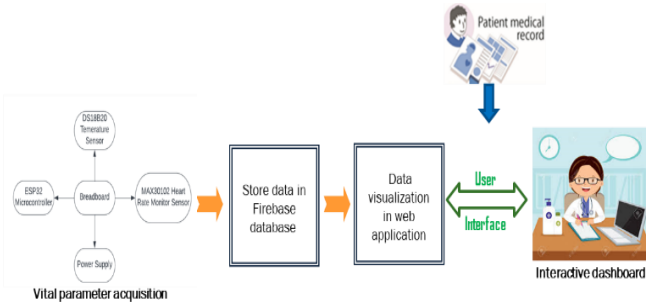


Fig. 1 Proposed IoT system for vital sign assessment

The gathered data is sent wirelessly to store in the Firebase database. The system implements a burst transmission method to merge multiple sensor readings into one frame in order to save overhead and, in addition, save energy. It implements the Time Division Multiple Access (TDMA) protocol to manage communication among sensor nodes, where individual time slots are assigned for each node to send data. This energy-conserving approach keeps sensor nodes turned off during idle time slots. The CSMA/CA protocol with RTS/CTS (Ready to Send / Clear to send) also prevents collisions and reduces delays to ensure safe transmission of data.

Lastly, an interactive dashboard is constructed based on a web application to monitor in real-time, visualize data, and send emergency alerts through SMS

or email. Individual users or physicians can view the interactive dashboard through login to the web application and can export the data into an Excel sheet to analyze in depth or for clinical documentation. They can also monitor their health data and create reports for personal usage or medical consultation.

1.1 Hardware components of the proposed system

The proposed system illustrated in Fig. 2, shows the working model along with the connections of each component. The setup demonstrates the integration of sensors and IoT to collect, analyze, and transmit health data patient monitoring in a compact and portable form.

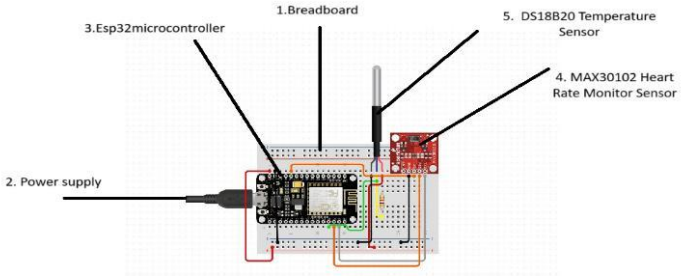


Fig. 2 Working model of the proposed system

1. Breadboard: This is a perforated board used to connect electronic components without soldering temporarily. It provide a platform to connect and test components like the microcontroller, sensors and actuators for prototyping and testing circuits. The breadboard facilitates the seamless integration of wires and sensors, ensuring secure connections and signal flow between the components.

2. Power supply: This is the source of electrical energy for the entire system. It provides the necessary power to operate all the connected components. A USB cable powers the system and facilitates communication.

3. ESP32 Microcontroller: This is the central processing unit of the proposed system. It receives data from all the sensors,

processes the data, and transmit the data to store them in a database for performs necessary calculations and analysis. It serves as the bridge

between sensors and the web application. We use the NodeMCU-32 to gather data from both the DS18B20 temperature sensor and the MAX30102 heart rate monitor sensor, then transmit this data in real-time to a Firebase real-time Database. This microcontroller is powered by the ESP32 chip, which offers robust processing power, built-in Wi-Fi, and Bluetooth connectivity, making it highly suitable for wireless data transmission in IOT applications. Its low power consumption and high performance ensure continuous, reliable monitoring, while its compatibility with multiple sensors allows for flexible integration. Each sensor has a specific role and works wirelessly, collecting physiological data at defined intervals set by healthcare providers.

4. MAX30102: Heart rate sensor: We have utilized the MAX30102 sensor in the current research to monitor SpO_2 and pulse rate with accurate and real-time observation of vital signs. The blood pressure (BP) is also approximated via a computational algorithm that utilizes pulse wave data. The acquired data are received from the fingertip sensor to a web dashboard via Firebase, enabling remote access for the users and healthcare professionals. It enables effortless, uninterrupted tracking of health with effective functioning with the help of cloud and IoT technologies to enhance accessibility and achieve real-time awareness of one's health.

5. DS18B20 temperature sensor: This sensor measures a person's body temperature. The DS18B20 temperature sensor has been utilized to measure body temperature. It provides a reliable, digital output with a high degree of accuracy (±0.5°C) and a wide temperature range, making it suitable for precise temperature readings essential for vital sign monitoring.

1.1 Software components of the proposed system

The proposed system utilizes software components to develop a web application for the collection, processing, and transmission of health data. The web application consists of four primary web pages, User registration, User login, Doctor' dashboard, and user's dashboard.

The user registration page shown in Fig. 3 presents a clean and to-the-point signup form, for entering basic user information. Users are requested to enter their full name, mobile number, and email address, and enter a secure password. To enable a user-specific experience, users are also requested to enter their user type such as "Doctor." On entering all the required fields, a plain click on the "SIGNUP" button initiates account creation.



Fig.3 User registration

For registered users, there is an easily accessible "Sign in now" link for easy access to their current accounts. Fig. 4 illustrates a user login page. It is a simple web page that has a simple login form particularly for doctors. It needs to input user's registered email address and password. For those who are not yet members of the platform, there is an easily accessible "Sign up" facility for opening a new account.

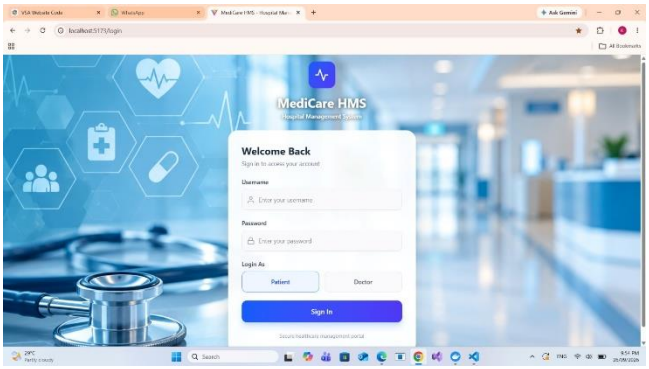


Fig.4 User login

An interactive dashboard shown in Fig. 5 is designed to show real-time data obtained with the proposed IoT-based vital sign monitoring system. The web page shows vital parameters such as the patient's name, age, systolic and diastolic blood pressure values, pulse rate, body temperature, SpO2 levels, and medications administered in tabular form. The web page is updated automatically whenever the patient enters their vital signs as a new row in the table. The real-time system ensures that medical staff have access to up-to-date and correct patient information, enabling timely decision-making and intervention. In addition, the web page is also equipped with functionalities such that users can easily update critical patient information such as age, contact, address, and medications prescribed. Such flexibility ensures that patient records are current and relevant at all times.

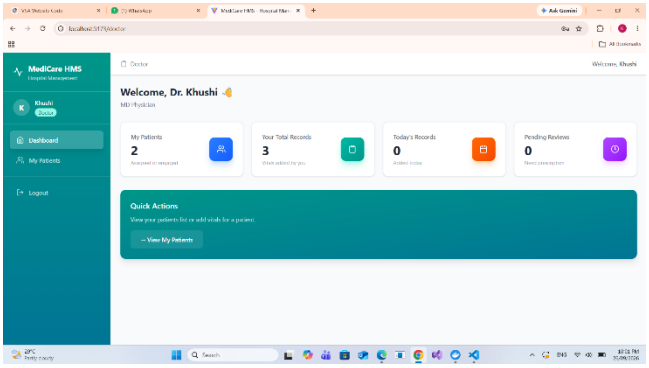


Fig.5 Doctor' dashboard

For ease of use, the page has friendly navigation buttons for "Home," "Patient Details," and "Logout." The buttons are strategically located to allow ease of use, thus healthcare practitioners can navigate around the system with minimal effort. Further, the "Patient Details" page offers a deeper review of the patient's history, whereby practitioners are able to view prior readings, trends, and changes over time. One of the features of the dashboard is the option to download all patient data in Excel. This option offers massive value by allowing healthcare professionals to further analyze

patient data offline, share it with others, or import it into other healthcare management systems. The ability to export data to Excel assists in further analysis and support for better-informed clinical decisions.

Additionally, the web interface incorporates sophisticated data visualization tools, such as graphs and charts, to provide a visual representation of key health metrics. These visual aids make it easier for healthcare professionals to identify trends, fluctuations, and potential areas of concern. This real-time visualization not only improves data accessibility but also allows healthcare providers to track patient progress, detect anomalies early, and respond proactively. A similar interface namely “User’s dashboard” has been provided for users other than doctors. Fig. 6 shows this web page.

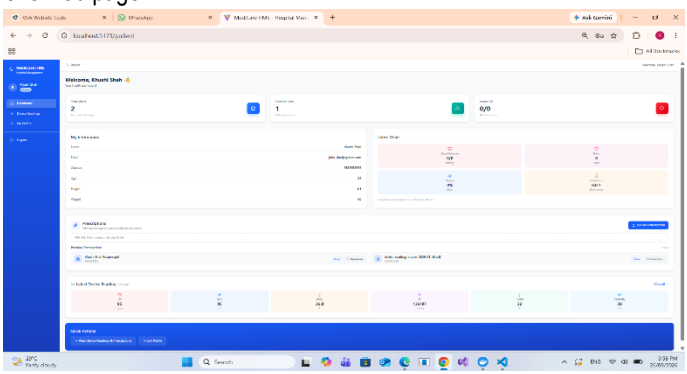
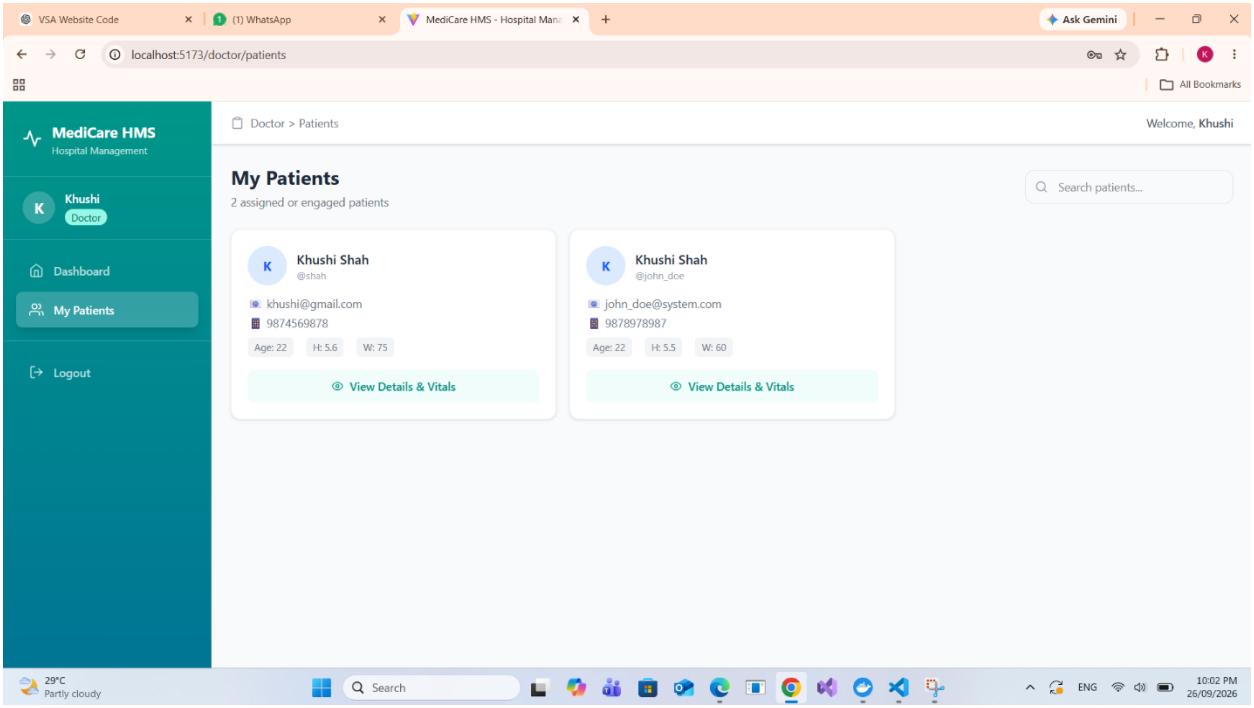
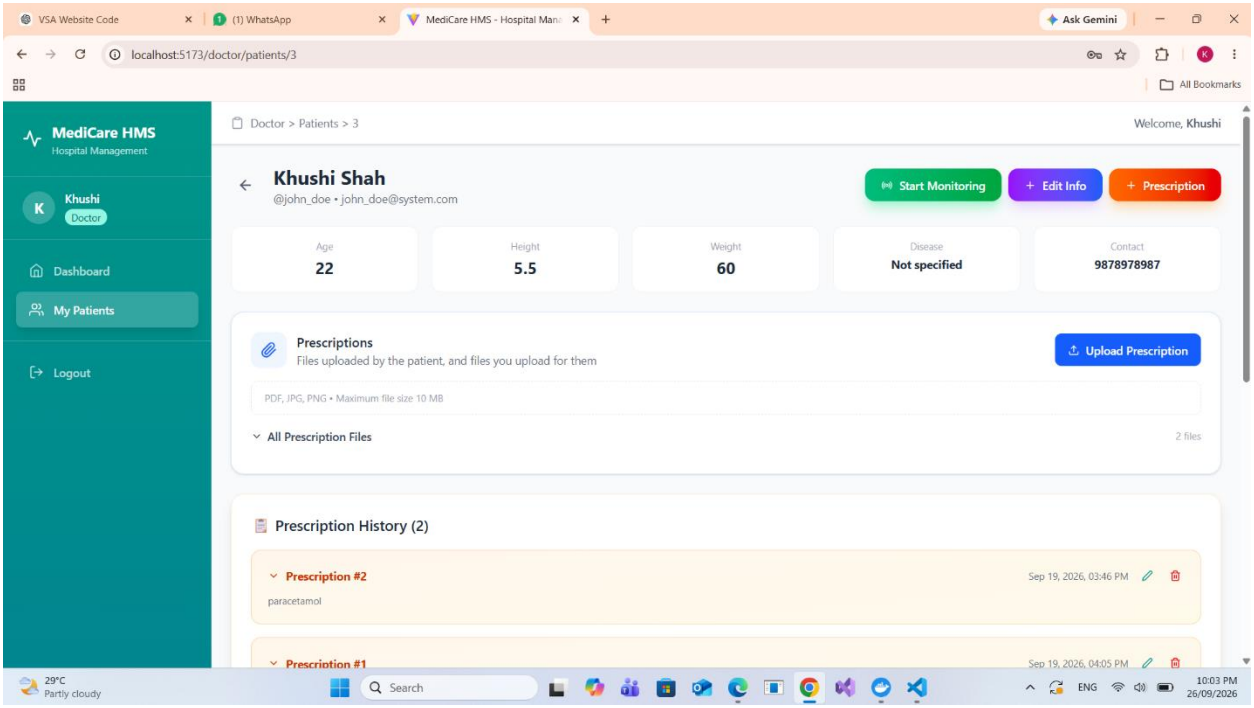


Fig.6 User’s dashboard

An interactive dashboard shown in Fig. 7 is designed to facilitate patient management within the proposed IoT-based healthcare monitoring system. The web interface displays a list of patients associated with the doctor, presenting essential information such as the patient's name, username, email address, contact number, age, height, and weight. A search facility enables the doctor to locate specific patient records efficiently. Furthermore, the “View Details & Vitals” option provides access to detailed patient information, including available vital sign records and medical history. This interface supports organized patient management and enables healthcare professionals to access patient-specific information conveniently for clinical review and monitoring.



An interactive patient details interface shown in Fig. 8 provides comprehensive access to patient information within the proposed IoT-based healthcare monitoring system. The interface displays essential patient details, including name, age, height, weight, disease information, and contact number. It also provides functionalities to initiate vital sign monitoring, update patient information, and upload and manage prescription documents. The prescription history section maintains previously recorded prescription details, including medication names and timestamps, with options to edit or delete entries. These features facilitate centralized management of patient records and medical prescriptions, supporting convenient access to relevant healthcare information for clinical review and patient care.



The patient profile interface presented in Fig. 9 enables patients to view and update their personal information within the proposed IoT-based healthcare monitoring system. The interface displays the patient's name, username, email address, assigned doctor, and role, along with editable fields for contact number, age, height, and weight. The email address and username are displayed as read-only fields

to maintain account consistency. A “Save Changes” function allows patients to update their editable profile information. This interface supports the maintenance of up-to-date patient records and facilitates convenient access to personal information within the healthcare platform.

2. Results and Discussion

The clinical performance of the proposed VSIGNS IoT-based vital sign monitoring system was evaluated in a comparative study involving 150 participants. The Clinical Evaluation Report states that there were no participant dropouts and no missing data, and that all 150 participants were included in the analysis. The evaluation covered heart rate, systolic blood pressure, diastolic blood pressure, oxygen saturation (SpO_2), and body temperature. Measurements from the VSIGNS test product were compared with corresponding reference-device measurements; blood pressure was also compared with the reference procedure described in the report. The results below reproduce the aggregate statistics reported in the clinical evaluation and do not represent newly calculated participant-level results.

Comparative Results of Vital Sign Measurements

Table 1 summarizes the reported mean and standard deviation (SD) for VSIGNS and the reference device. Mean differences are calculated as VSIGNS minus the reference-device mean using the reported rounded values. Pearson correlation coefficients and two-tailed p-values are taken from the clinical report.

Parameter	VSIGNS Mean ± SD	Reference Mean ± SD	Mean difference	Pearson r	Two-tailed p	n
Heart rate (bpm)	86.31 ± 13.73	87.57 ± 14.16	−1.27 bpm	0.9375	0.002067	150
Systolic BP (mmHg)	124.29 ± 16.28	124.38 ± 16.48	−0.09 mmHg	0.8705	0.898888	150
Diastolic BP (mmHg)	78.31 ± 7.44	78.55 ± 7.95	−0.24 mmHg	0.8149	0.533282	150
SpO_2 (%)	98.44 ± 0.73	98.40 ± 0.91	+0.04 percentage points	0.4608	0.572476	150
Body temperature (°F)	97.26 ± 0.78	97.22 ± 0.75	+0.05 °F	0.8751	0.149577	150

Table 1. Summary of VSIGNS and reference-device measurements in the 150-participant clinical evaluation. The mean differences are calculated from rounded group means.

Heart Rate

The mean heart rate recorded by VSIGNS was 86.31 ± 13.73 bpm, compared with 87.57 ± 14.16 bpm for the reference device. The difference between the rounded group means was approximately −1.27 bpm. The reported Pearson correlation was 0.9375, indicating a strong positive association between the two sets of readings. The report gives a two-tailed p-value of 0.002067 for the test-product versus reference-device comparison. Therefore, although the group means are close, the difference was statistically significant at the conventional 0.05 level. Correlation describes association and does not, by itself, establish interchangeability.

Systolic Blood Pressure

The mean systolic blood pressure measured by VSIGNS was 124.29 ± 16.28 mmHg, while the reference device recorded 124.38 ± 16.48 mmHg. The difference between the rounded group means was approximately −0.09 mmHg. The reported Pearson correlation coefficient was 0.8705, indicating a strong positive association. The two-tailed p-value was 0.898888, so the report’s paired comparison did not identify a statistically significant difference between the group means. Nevertheless, group-level similarity does not show how closely each participant’s readings agreed; individual-level error and agreement analyses are needed for a more complete assessment of BP estimation performance.

Diastolic Blood Pressure

VSIGNS recorded a mean diastolic blood pressure of 78.31 ± 7.44 mmHg, compared with 78.55 ± 7.95 mmHg for the reference

device. The difference between the rounded group means was approximately −0.24 mmHg. The Pearson correlation coefficient was 0.8149, indicating a positive association between the readings. The reported two-tailed p-value was 0.533282, which did not indicate a statistically significant difference between the group means. As with systolic BP, correlation and comparison of means should not be treated as a substitute for participant-level agreement or clinical validation of the estimation method.

Oxygen Saturation (SpO_2)

The mean SpO_2 recorded by VSIGNS was 98.44 ± 0.73%, while the reference pulse oximeter recorded 98.40 ± 0.91%. The difference between the rounded means was approximately +0.04 percentage points. The report gives a Pearson correlation coefficient of 0.4608, indicating a moderate positive association and a lower correlation than those reported for heart rate, blood pressure, and body temperature. The two-tailed p-value was 0.572476, which did not indicate a statistically significant difference between the group means. The close means should be interpreted alongside the moderate correlation and the need for individual-level agreement analysis.

Body Temperature

The mean body temperature reported for VSIGNS was 97.26 ± 0.78 °F, compared with 97.22 ± 0.75 °F for the reference thermometer. The difference between the rounded means was approximately +0.05 °F. The reported Pearson correlation coefficient was 0.8751, indicating a strong positive association between the measurement sets. The two-tailed p-value was 0.149577, which did not indicate a statistically significant difference between the group means. These aggregate findings do not replace an assessment of individual measurement errors or confirmation that sensor placement and measurement procedures are appropriate for the intended use.

Comparison with the Reference Procedure

The Clinical Evaluation Report also compares VSIGNS with a reference procedure for heart rate and blood pressure. For heart rate, the reported means were 86.31 bpm for VSIGNS and 87.29 bpm for the procedure, with Pearson correlation 0.8899 and a two-tailed p-value of 0.059132. For systolic BP, the corresponding means were 124.29 and 123.47 mmHg, with Pearson correlation 0.8938 and a two-tailed p-value of 0.171221. For diastolic BP, the means were 78.31 and 77.51 mmHg, with Pearson correlation 0.7812 and a two-tailed p-value of 0.05651. These results indicate positive associations. The diastolic BP p-value is close to 0.05 and should not be described as proof of equivalence.

Discussion

Across the five assessed parameters, the reported VSIGNS and reference-device group means were numerically close. The strongest association was reported for heart rate ($r = 0.9375$), followed by systolic BP ($r = 0.8705$), body temperature ($r = 0.8751$), and diastolic BP ($r = 0.8149$). The reported SpO_2 correlation ($r = 0.4608$) was comparatively lower. The paired comparison for heart rate showed a statistically significant difference ($p = 0.002067$), whereas the reported two-tailed p-values for systolic BP, diastolic BP, SpO_2, and body temperature were above 0.05. The results should therefore be discussed parameter by parameter rather than summarized as universal agreement across all measurements.

Pearson correlation measures association, not the agreement or accuracy of individual readings. Similar group means can coexist with clinically important errors for individual participants. A more complete evaluation would include participant-level paired differences, mean absolute error, root mean square error, confidence intervals, and an appropriate agreement analysis such as Bland–Altman analysis, where the underlying paired data are available. For blood pressure estimation, the validation method and acceptance criteria should be stated clearly.

Web-Based Monitoring Interface

The web application complements the sensor and microcontroller components by presenting patient-specific records through doctor and patient interfaces. Figures 5–9 illustrate the monitoring dashboard, doctor's patient list, patient details and prescription management, and patient profile management. The device-readings page summarizes recorded measurements and provides access to historical readings and doctor-review requests. The doctor interface supports patient lookup and access to patient details, while the patient interface allows users to review recorded readings and update permitted profile fields. These functions provide a structured means of accessing recorded data and support clinical review. Claims of automatic real-time updating should be retained only to the extent that the implemented data-refresh mechanism has been verified.

Transmission Delay, Database Performance, and Energy Consumption

The earlier manuscript refers to transmission delay, database performance, and energy consumption. However, numerical measurements, test conditions, sample counts, and measurement procedures for these metrics were not identified in the clinical summary used for this revision. Consequently, no quantitative conclusions about negligible delay, Firebase scalability, or low power consumption are added here. If these experiments have been performed, this subsection should include measured latency and its start/end definitions, number of trials, database load and concurrency conditions, current or power measurements, supply voltage, and test duration.

Limitations

The reported clinical results are aggregate statistics from 150 participants. Participant-level paired readings and full error distributions were not included in the summary used for this section; therefore, individual-level accuracy, limits of agreement, and error rates cannot be independently derived here. Correlation values should not be interpreted as clinical equivalence. The results support further evaluation of the integrated monitoring platform but should not alone be used to claim that every measurement is clinically interchangeable with a reference device.

Overall Findings

The clinical evaluation report documents a 150-participant comparison of VSIGNS with reference devices and reports similar group means for heart rate, systolic and diastolic blood pressure, SpO_2, and body temperature. The strength of association varied by parameter, and the heart-rate comparison showed a statistically significant difference in the reported paired test. Together with the web-based monitoring interfaces, these findings support the feasibility of an integrated IoT-based vital-sign monitoring platform. Further participant-level agreement analysis and documented system-performance testing are needed before making stronger claims about clinical accuracy, real-time latency, scalability, or energy efficiency.

Clinical Trial Registration: The study was registered with the Clinical Trials Registry–India (CTRI) under registration number CTRI/2025/06/089075 on 18 June 2025. The study, titled “Clinical Performance Testing of System and Method for Real Time Vital Sign Monitoring,” was conducted at Parul Sevashram Hospital, Gujarat, and included 150 participants.

3. Conclusion

Accurate and timely vital sign monitoring is required for effective patient care in healthcare. The system proposed in this paper based on IoT provides an effective solution to continuous and real-time monitoring of vital signs with overcoming the defects of conventional health care systems which are based on intermittent check-up and manual reports. The inclusion of IoT for vital sign monitoring into healthcare systems is a crucial milestone in the evolution of patient care. Such vital parameters monitored via the suggested system are critical to the early diagnosis of diseases, timely intervention, and proper diagnosis. Additionally, remote monitoring of vital signs enables timely intervention, fewer hospital visits, and effective management of chronic diseases, which results in improved patient outcomes.

The interactive dashboard improves the overall performance of the proposed system. Moreover, primary features such as real-time data visualization, robust user authentication, and fast data export features allow the proposed system for effortless integration into clinical processes. Further, cost-effectiveness of the proposed system lessens the burden of healthcare provider’s at large scale. The performance of the system has shown adequate accuracy and dependability in the measurement of vital signs, and the data strongly corresponded to standard medical devices.

Future research will center on enhancing precision and minimizing errors between the projected IoT-based system and conventional medical equipment. Progress will also concentrate on widening the capabilities of the system by including other sensors like ECG, for complete monitoring. In addition, the use of machine learning methods to construct predictive models would offer better patient health insights for even more personalized treatment.

4. Acknowledgments

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