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Revolutionizing Modern Healthcare Delivery through Sustainable IoT-based Continuous Real-Time Patient Monitoring

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The advancement of Internet of Things (IoT) technology has revolutionized healthcare by enabling continuous, real-time monitoring of patients' vital signs. This project introduces the "MedSen IoT", a cutting-edge medical device designed to measure and monitor critical health parameters such as blood oxygen saturation blood oxygen saturation (SpO2), heart rate (BPM), body temperature, room temperature, and room humidity. MedSen IoT combines sophisticated sensor technology with IoT connectivity to offer a comprehensive, user-friendly health monitoring solution. The device captures real-time data, which is then wirelessly transmitted to a centralized cloud platform. Healthcare professionals and users can access and analyze this data through a dedicated mobile application, facilitating timely interventions and personalized healthcare management. Key features of MedSen IoT include high-precision sensors, seamless wireless communication, and an intuitive data analytics platform. The device is designed for ease of use, making it suitable for both clinical environments and home settings. By leveraging IoT technology, MedSen IoT aims to enhance patient care, improve health outcomes, and reduce the burden on healthcare systems.

Keywords: *sustainable healthcare systems; sustainable digital health; internet of things; blood oxygen saturation.*

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1. Introduction

The primary motivation behind this project is to address the challenges in effective and sustainable health monitoring [1–3]. With the increasing number of patients requiring continuous monitoring, especially those with chronic illnesses, there is an urgent need for solutions that provide accurate and easy-to-use real-time monitoring [4–7]. MedSen IoT aims to meet this need by offering technology that can deliver continuous health data, enabling quicker and more timely interventions by healthcare professionals. This will not only improve patients' quality of life but also reduce the burden on healthcare facilities by allowing remote monitoring.

Advances in sensor technology and wireless communication have paved the way for reliable IoT devices in different areas [8–11], including medical applications. Numerous studies have shown that real-time health monitoring can significantly improve patient outcomes by allowing early detection of worsening medical conditions [12–14]. MedSen IoT builds on this foundation of research, incorporating proven sensor technology to measure critical health parameters such as SpO2, BPM, body temperature, room temperature, and humidity. By transmitting data wirelessly to a cloud platform, MedSen IoT leverages the power of cloud computing and data analytics to provide valuable insights to users and healthcare professionals [15–18].

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The IoT technology holds immense potential to revolutionize how we monitor and manage health. MedSen IoT is a concrete example of how this technology can be applied to create more effective and efficient health monitoring systems [19–22]. Using high-precision sensors and wireless connectivity, MedSen IoT can collect and transmit health data in real-time, allowing for more continuous and detailed monitoring [23, 24]. Additionally, the centralized cloud platform enables this data to be accessed from anywhere, providing flexibility and convenience for users and healthcare professionals in accessing and analyzing health information.

MedSen IoT is designed for use in both clinical settings and at home, offering flexibility and convenience to users. In clinical environments, this device can help medical staff monitor patients' conditions better, reducing the need for time-consuming routine checks. At home, MedSen IoT provides patients and their families with peace of mind by enabling continuous health monitoring without the need to leave home. The accompanying mobile application also makes it easy for users to view and understand their health data, encouraging them to be more proactive in managing their own health.

The main contribution and novelty of this work as follows:

(a) The first step in addressing the problem is to develop and integrate high-precision sensors capable of accurately measuring critical health parameters such as SpO2, heart rate, body temperature, room temperature, and humidity.

(b) To facilitate real-time monitoring, the project will integrate IoT connectivity within the MedSen IoT device. This includes developing a robust wireless communication system that ensures seamless and secure data transmission from the device to the cloud platform.

(c) A user-friendly mobile application will be created to allow users and healthcare professionals to easily access and analyze health data. The app will feature intuitive dashboards, real-time alerts, and data visualization tools to facilitate understanding and decision-making. Additionally, the app will support personalized health management by allowing users to set goals and track their progress over time.

2. Materials and methods

The methodology adopted for the development of MedSen IoT encompasses the design and implementation of an integrated system comprising hardware sensors, a microcontroller platform, wireless communication modules, and cloud-based data visualization through a mobile application. The overall process is structured into the following phases.

2.1. System architecture design

The MedSen IoT system was designed as a compact, integrated health monitoring platform centered around the ESP32 microcontroller. The ESP32 was selected due to its dual-core processor, low power consumption, and built-in wireless communication capabilities (Wi-Fi and Bluetooth), making it ideal for real-time IoT applications. This microcontroller serves as the central hub that acquires, processes, and transmits data from a suite of medical and environmental sensors. Among the sensors used, the MAX30102 module plays a critical role by providing real-time measurements of blood oxygen saturation (SpO2) and heart rate (BPM). This sensor, commonly used in wearable health devices, communicates with the ESP32 via the I2C protocol and offers high accuracy in pulse oximetry data. For monitoring body temperature, the DS18B20 digital temperature sensor was implemented using the one-wire communication protocol, known for its reliability and simplicity in digital signal transmission. Additionally, the DHT22 sensor was integrated to capture ambient temperature and humidity data. Each of these sensors was strategically chosen for its precision, low latency, and compatibility with the ESP32 platform.

To support local visualization of real-time data, a compact OLED display was incorporated into the system, interfacing with the ESP32 via I2C to display key parameters such as SpO2, BPM, and temperature readings. This allows patients or caregivers to immediately view health metrics without the need for a smartphone or external display. All components were initially mounted on a breadboard for prototyping, ensuring ease of reconfiguration and testing during the development phase. Special attention was given to the wiring layout and power management to ensure stable operation. Jumper wires and resistors were used to establish reliable electrical connections, including a pull-up resistor on the DS18B20's data line to ensure signal integrity. The overall architecture reflects a modular design philosophy, enabling future scalability to include additional sensors or replace existing modules without requiring significant hardware redesign. This system forms the foundational layer of the MedSen IoT device, enabling the subsequent stages of data transmission, cloud integration, and remote health monitoring.

2.2. Sensor integration and data acquisition

The integration of sensors into the MedSen IoT system was executed with a focus on ensuring precise, real-time acquisition of critical health and environmental parameters. The process began by interfacing the MAX30102 pulse oximeter sensor with the ESP32 microcontroller to measure both blood oxygen saturation (SpO2) and heart rate (BPM). This sensor communicates through the I2C protocol, allowing efficient two-wire data transmission (SDA and SCL) with minimal resource usage on the microcontroller. Due to its sensitivity to ambient light and placement accuracy, calibration and positioning were carefully tested during implementation. For measuring body temperature, the DS18B20 sensor was selected due to its high accuracy and digital output. It uses a one-wire protocol, which enables communication using a single data line in conjunction with a mandatory pull-up resistor to maintain signal stability. To capture room temperature and humidity, the DHT22 sensor was integrated. This sensor provides digital readings and was connected to a general-purpose input/output (GPIO) pin on the ESP32. Each sensor was configured in the microcontroller's firmware using dedicated libraries, enabling the accurate interpretation of raw data into human-readable values.

The data acquisition process was controlled by the ESP32's internal timer and interrupt handling mechanisms to ensure synchronized sampling from all sensors without data overlap or loss. The microcontroller's firmware, written using the Arduino IDE, includes sensor-specific drivers and logic for initializing, reading, and validating the data. To enhance system reliability, a filtering mechanism was implemented to remove outliers and noise from the collected data, especially for vital signs like heart rate, which are susceptible to fluctuation due to movement artifacts or external interference. Each reading was timestamped and temporarily stored in the ESP32's memory before being formatted for display and transmission. The OLED display presented this data in real-time, offering immediate feedback to users. In parallel, the ESP32 prepared the data for wireless transmission to the cloud platform, ensuring no interruption in the acquisition loop. This dual approach-local visualization and remote storage-ensured both accessibility and traceability of the health metrics. Collectively, the seamless integration of these sensors and the robust data acquisition strategy laid the groundwork for an efficient, real-time health monitoring system tailored to clinical and home environments.

2.3. Wireless communication and cloud integration

To enable real-time remote health monitoring, the MedSen IoT system employs the built-in Wi-Fi module of the ESP32 microcontroller for wireless data transmission. Once the sensor data is collected and processed, it is formatted and sent via Wi-Fi to a cloud-based Internet of Things (IoT) platform. Among various available platforms, Blynk was selected due to its seamless compatibility with the ESP32, minimal setup requirements, and robust support for real-time data handling. The ESP32 communicates with the Blynk cloud server using Blynk's libraries and authentication tokens, ensuring secure and consistent data transmission. This architecture eliminates the need for complex back-end development, allowing for quick deployment and scalability. The transmission process is optimized to handle both individual data points and batch updates, maintaining the system's responsiveness even in fluctuating network conditions.

On the user side, Blynk offers intuitive mobile and web applications that serve as the front-end interface for data visualization and interaction. Through the Blynk dashboard, real-time readings from the sensors-such as SpO2, heart rate, body temperature, room temperature, and humidity-are displayed using gauges, charts, and alert widgets. Users and healthcare providers can monitor these metrics continuously and receive push notifications when any parameter exceeds predefined thresholds. The interface supports historical trend analysis, enabling pattern recognition and long-term health tracking. Furthermore, Blynk allows customization of the dashboard layout, enabling personalized experiences for different user needs. This integration of wireless communication with a cloud-based platform not only enhances accessibility and convenience but also supports timely medical decision-making by providing immediate visibility into a patient's vital signs, regardless of their physical location.

2.4. Mobile application and dashboard configuration

The mobile application and dashboard configuration play a vital role in the MedSen IoT system by providing users with real-time access to health data through an intuitive and interactive interface. Utilizing the Blynk platform, a customized dashboard was developed within the Blynk mobile app, allowing for seamless integration with the ESP32 microcontroller. The dashboard features a variety of user-friendly widgets, including gauges, value displays, graphs, and notification alerts, each mapped to specific health parameters such as SpO2, BPM, body temperature, room temperature, and humidity. These widgets are updated in real-time as the ESP32 sends data to the cloud. The layout is designed to be visually clear and easy to interpret, ensuring that users, including patients and healthcare providers, can quickly assess health conditions without the need for technical expertise.

Additionally, the dashboard supports dynamic data logging and historical trend visualization, enabling users to track changes in vital signs over time. This functionality is particularly beneficial for managing chronic health conditions, as it allows users to observe fluctuations and identify potential health risks early. The Blynk app also includes threshold-based alert systems that notify users via smartphone notifications when any parameter falls outside of the normal range, prompting timely intervention. Furthermore, the dashboard is accessible from both mobile and web platforms, ensuring flexibility and remote accessibility. Customization features allow healthcare providers to tailor the dashboard layout to suit specific monitoring needs, making it adaptable for different clinical scenarios or personal preferences. This mobile application and dashboard configuration not only enhances user engagement and awareness but also strengthens the overall effectiveness of the MedSen IoT system in delivering continuous, data-driven healthcare monitoring.

2.5. Prototype development and testing

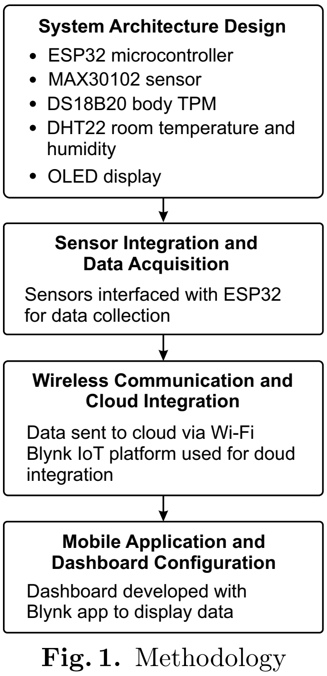

Fig. 1. Methodology of MedSen IoT.

The prototype development of the MedSen IoT system began with assembling all core components on a breadboard to allow flexibility during initial configuration and troubleshooting. This setup included the ESP32 microcontroller, MAX30102 pulse oximeter sensor, DS18B20 temperature sensor, DHT22 humidity and ambient temperature sensor, and an OLED display for local data visualization. Each component was carefully connected using jumper wires, with necessary pull-up resistors and power considerations addressed to ensure stable operation. The firmware was developed and uploaded via the Arduino IDE, incorporating libraries specific to each sensor module. Once the hardware was configured, the functionality of each sensor was individually verified to ensure accurate signal acquisition, processing, and transmission. The OLED display provided immediate feedback, aiding in real-time validation during development.

Following successful integration, the complete prototype underwent a series of tests in both simulated clinical and home environments. The system was exposed to varying temperature, humidity, and lighting conditions to evaluate sensor stability and accuracy across different scenarios. Test results were compared against standard medical instruments to verify consistency and reliability. Communication stability was also assessed by continuously transmitting data to the Blynk platform over extended periods to simulate real-world use. Both the mobile app interface and the cloud dashboard were monitored to ensure synchronized updates and correct threshold alert functions. The testing phase confirmed that the MedSen IoT prototype was capable of capturing, processing, and transmitting vital health data effectively, offering a reliable solution for continuous patient monitoring in diverse settings. These outcomes validated the design approach and laid a strong foundation for further refinement and eventual product deployment. Methodology of this work can be seen in Figure 1.

3. Results and discussion

The MedSen IoT project represents a significant advancement in the integration of sensor technology, IoT connectivity, and cloud-based data analytics within the healthcare sector. At its core, the device utilizes cutting-edge sensors to measure critical health parameters such as blood oxygen saturation (SpO2), heart rate (BPM), body temperature, room temperature, and humidity with high precision and reliability. These advanced sensors ensure that the health data captured is accurate and dependable, making the device suitable for both clinical settings and home use. This high level of precision in data collection sets MedSen IoT apart from many existing health monitoring solutions [25–27].

A key feature of MedSen IoT is its robust IoT connectivity, which enables seamless, real-time transmission of health data. By leveraging wireless communication protocols such as Bluetooth, Wi-Fi, and cellular networks, the device can continuously send data to a centralized cloud platform [28, 29]. This connectivity ensures that health data is always current and accessible, facilitating remote monitoring and enabling timely medical interventions. The ability to transmit data in real-time is crucial for continuous health monitoring and immediate response to potential health issues.

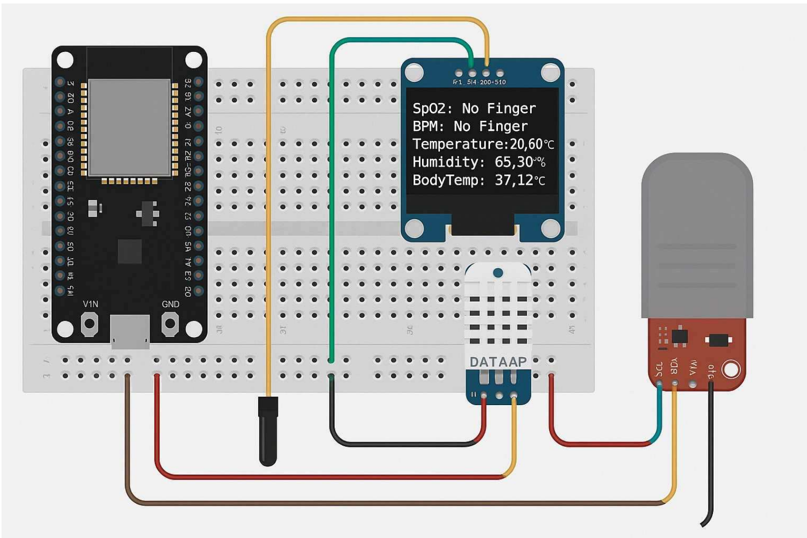

Fig. 2. Schematic of ESP32 based digital health monitoring system.

Figure 2 shows a digital health monitoring system built using an ESP32 microcontroller connected to three key sensors: the MAX30102, DHT22, and DS18B20, along with an OLED display to present the collected data. The ESP32 acts as the central processor, gathering sensor readings via digital interfaces. On the right side of the image, the MAX30102 sensor module is visible and is used to measure blood oxygen saturation (SpO2) and heart rate (BPM). This sensor typically comes with a finger clip and communicates with the ESP32 through I2C using the SDA and SCL pins. At the center of the setup, the OLED screen displays real-time readings such as SpO2, BPM, room temperature, humidity, and body temperature.

The DHT22 sensor, located at the lower center of the breadboard, measures ambient temperature and humidity. It features three pins: VCC, GND, and DATA, with the data pin connected to a digital pin on the ESP32. To its left, the DS18B20 temperature sensor is used to monitor body temperature more accurately. It uses a one-wire communication protocol and requires a pull-up resistor for proper data transmission. All components are wired together on a breadboard using jumper cables and powered by the ESP32. This setup illustrates a neatly integrated and portable health monitoring system suitable for IoT-based medical applications.

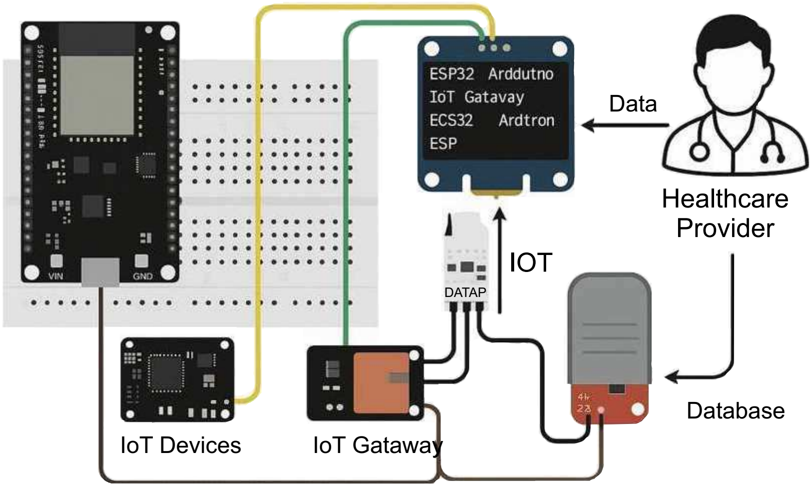

Fig. 3. Remote patient monitoring system architecture.

Figure 3 illustrates a comprehensive IoT-based healthcare system using the ESP32 microcontroller to collect, process, and transmit real-time patient data. On the left side of the diagram, a breadboard setup integrates multiple medical sensors, including a body temperature sensor, a humidity and room temperature sensor (DHT sensor), and a pulse oximeter for measuring SpO2 and heart rate. These sensors continuously gather vital health information, which is displayed on an OLED screen. The ESP32 microcontroller serves as the central processing unit, managing the input from all sensors and enabling wireless communication with the cloud.

In the center of the diagram, the system includes an IoT Gateway function embedded in the ESP32, which transmits collected sensor data to the cloud using the Blynk platform. Blynk acts as the cloud service and interface layer, allowing data to be visualized and stored remotely. Through the Blynk application, users can access real-time dashboards displaying metrics like room temperature, humidity, and body temperature, as well as monitor the status of the pulse and SpO2 sensors. This seamless integration between hardware and software enables scalable, secure, and efficient health monitoring capabilities.

On the right side, the diagram depicts a Healthcare Provider who receives and monitors the transmitted data through the Blynk mobile or web app. This allows doctors and caregivers to remotely access patient data, detect abnormalities, and make informed decisions without the need for physical presence. The use of Blynk ensures secure and user-friendly data visualization, supporting continuous patient care, especially for individuals with chronic conditions or those living in remote areas. Overall, the system architecture demonstrates a practical and impactful application of IoT technology in modern healthcare.

Figure 4 shows cases a compact hardware device equipped with various sensors and a display screen. The box-like structure appears to house electronic components, likely connected to external peripherals like the antenna seen on top and the cables extending out. The small screen displays data readings such as "SpO2", "Heart rate", and temperature values for "Room", "Headroom", and "Bodyroom". This suggests the device is designed for monitoring vital signs or environmental parameters. The device's display indicates it is capable of measuring oxygen saturation (SpO2) and heart rate, although no finger is currently detected on the sensor. This function implies the use of a pulse oximeter sensor module, commonly utilized in health monitoring systems. Additionally, the temperature readings in various zones indicate the presence of multiple thermal sensors, enabling precise environmental or body temperature tracking.

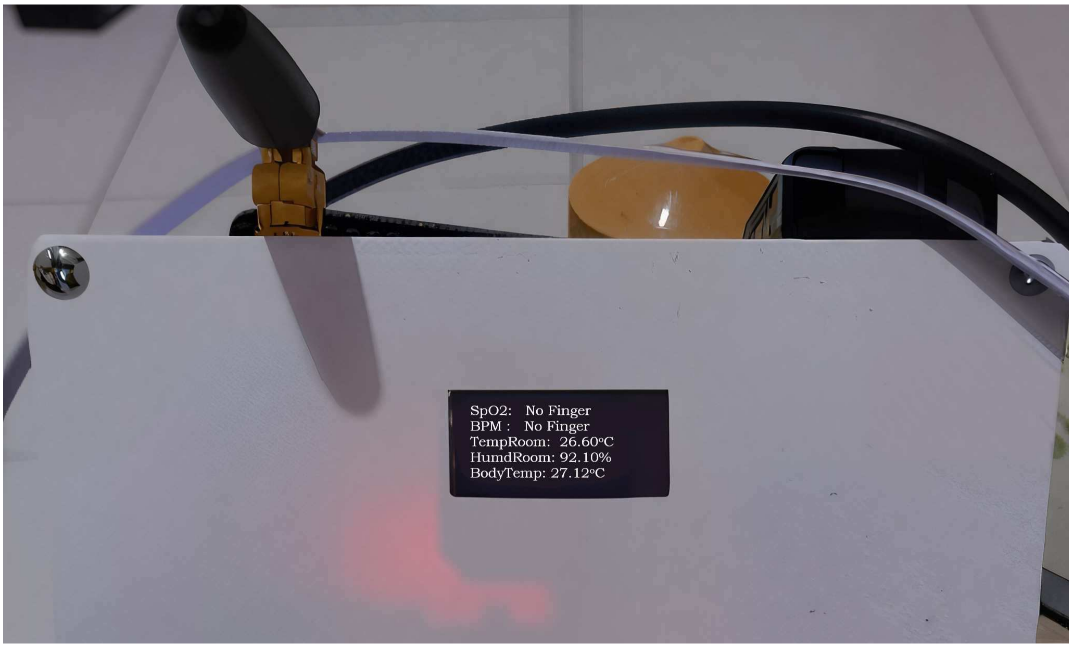

Fig. 4. Hardware Medsen IoT.

The attached antenna and visible cables suggest that the device may also have wireless communication capabilities, possibly to send collected data to an external system or application. Such hardware is often used in health monitoring, research, or IoT-based applications where remote access and real-time data collection are essential. The compact design and multi-functional capabilities highlight its potential use in portable or embedded systems.

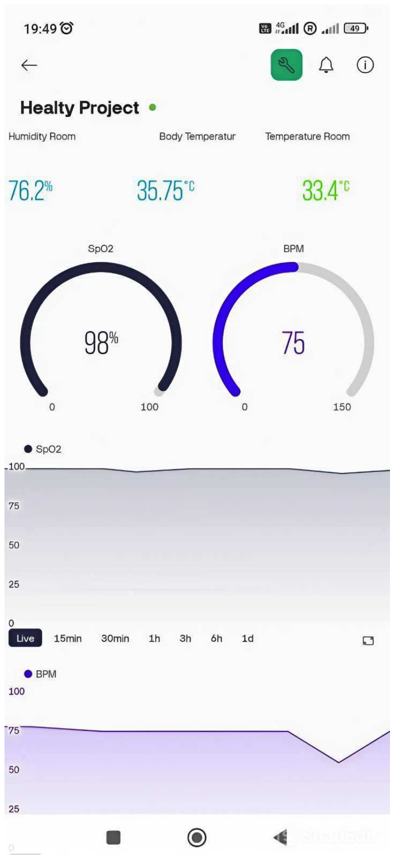

Fig. 5. The result of monitoring healtcare.

Figure 5 displays live health monitoring data collected as part of a "Healthy Project". The key parameters tracked include room humidity, body temperature, room temperature, blood oxygen saturation (SpO2), and heart rate in beats per minute (BPM). The interface also features gauges and a timeline graph for continuous monitoring. Each metric serves a specific purpose in evaluating an individual's or environment's health status. The first metric, room humidity, is shown at 76.2%. This value represents the relative humidity in the room, which is crucial for comfort and health. High humidity may cause discomfort and promote mold growth, while low humidity can lead to dryness and respiratory issues. The displayed humidity seems moderate to high, likely indicating an indoor environment that could feel humid.

Body temperature is displayed as 35.75°C, slightly below the average human body temperature range of 36.1–37.2°C. While not drastically low, it may indicate mild hypothermia or inaccurate measurement conditions. It is important to cross-check such values with other tools or methods for reliable conclusions. The SpO2 and BPM metrics represent vital health indicators. The SpO2 is at 98%, a healthy oxygen saturation level, indicating efficient oxygen transport in the bloodstream. The BPM is 75, within the normal resting heart rate range (60–100 BPM for adults). The stability in both metrics suggests no immediate health concerns, assuming the individual is at rest. Lastly, the graph at the bottom tracks BPM over time. The live data point is steady at 75 BPM, but earlier fluctuations are visible. The timeline options (e.g., 15 min, 30 min, 1 h) indicate the potential to analyze trends over different durations. Such data is valuable for detecting irregular patterns or stress responses. The interface provides a clear, user-friendly way to monitor and interpret health and environmental metrics in real-time.

4. Conclusion

The MedSen IoT project demonstrates the transformative potential of integrating advanced sensor technology, IoT connectivity, and cloud-based analytics in healthcare. By enabling real-time monitoring of critical health parameters such as SpO2, heart rate, and body temperature, this innovative device empowers both patients and healthcare professionals with actionable insights for timely and personalized interventions. Its user-friendly design and robust data analytics capabilities make it adaptable for both clinical and home settings, addressing the growing need for efficient and accessible health monitoring solutions.

Through the implementation of secure data transmission and compliance with regulatory standards, MedSen IoT ensures the reliability and privacy of sensitive health information. Additionally, its scalable architecture and future-proofing strategies lay a strong foundation for sustained relevance amidst evolving technological and healthcare needs.

The successful development and deployment of MedSen IoT underline its potential to enhance patient outcomes, reduce the strain on healthcare systems, and foster a proactive approach to health management. Future iterations may explore expanded capabilities and broader applications to further revolutionize healthcare delivery.

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Революціонізація сучасного медичного обслуговування завдяки сталому безперервному моніторингу пацієнтів у режимі реального часу на основі Інтернету речей

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Розвиток технології Інтернету речей (IoT) здійснив революцію в охороні здоров'я, забезпечивши безперервний моніторинг життєво важливих показників пацієнтів у режимі реального часу. Цей проект представляє "MedSen IoT" — передовий медичний пристрій, призначений для вимірювання та моніторингу критичних параметрів здоров'я, таких як насичення крові киснем (SpO2), частота серцевих скорочень (BPM), температура тіла, температура в приміщенні та вологість у приміщенні. MedSen IoT поєднує складну сенсорну технологію з підключенням до IoT, щоб запропонувати комплексне та зручне рішення для моніторингу здоров'я. Пристрій фіксує дані в режимі реального часу, які потім бездротовим способом передаються на централізовану хмарну платформу. Медичні працівники та користувачі можуть отримувати доступ до цих даних та аналізувати їх через спеціальний мобільний додаток, що сприяє своєчасному втручанню та персоналізованому управлінню охороною здоров'я. Ключові особливості MedSen IoT включають високоточні датчики, безперебійний бездротовий зв'язок та інтуїтивно зрозумілу платформу аналізу даних. Пристрій розроблений для простоти використання, що робить його придатним як для клінічних середовищ, так і для домашніх умов. Використовуючи технологію IoT, MedSen IoT прагне покращити догляд за пацієнтами, покращити результати здоров'я та зменшити навантаження на системи охорони здоров'я.

Ключові слова: *сталі системи охорони здоров'я; стале цифрове здоров'я; Інтернет речей; насичення крові киснем.*