

# Health Monitoring System

**Prof. A. P. Malode<sup>1</sup>, Ms. Shweta Ghatare<sup>2</sup>, Mr. Aniket Mande<sup>3</sup>,  
Mr. Girdharilal Dhanurkar<sup>4</sup>, Mr. Amit Shirpurkar<sup>5</sup>**

Professor, Department of Industrial IoT<sup>1</sup>  
Students, Department of Industrial IoT<sup>2-5</sup>

Priyadarshini College of Engineering, Nagpur, Maharashtra, India  
apm280374@gmail.com<sup>1</sup>, sghatare2021@gmail.com<sup>2</sup>, aniketmande445@gmail.com<sup>3</sup>  
girdharidhanurkar03@gmail.com<sup>4</sup>, amitshirpurkar5@gmail.com<sup>5</sup>

**Abstract:** *This project develops an IoT-based Health Monitoring System to continuously observe vital physiological parameters including SpO<sub>2</sub> (blood oxygen saturation), heart rate, and temperature in real time. The system is built using an ESP32 microcontroller connected to a MAX30102 sensor for measuring SpO<sub>2</sub> and pulse rate, and a DHT11 sensor for temperature sensing. The acquired data is displayed locally on an OLED screen and simultaneously transmitted to a Firebase Realtime Database via Wi-Fi for remote storage and access.*

*A web-based dashboard created with HTML, CSS, and JavaScript provides real-time visualization of patient data, historical trends, and an overall health status indicator. Using predefined threshold values, the system automatically categorizes the patient's condition as Normal or Risk, allowing early detection of abnormal conditions and timely intervention. The proposed system is cost-effective, scalable, and suitable for applications in home care, clinics, and telemedicine environments..*

**Keywords:** IoT, Health Monitoring System, ESP32, MAX30102, SpO<sub>2</sub> Monitoring, Heart Rate Monitoring, Temperature Sensor, Firebase Realtime Database, Web Dashboard, Remote Patient Monitoring, Real-Time Data Visualization

## I. INTRODUCTION

Healthcare systems across the world are undergoing a major transformation with the integration of digital technologies and intelligent monitoring solutions. Continuous observation of vital health parameters such as blood oxygen saturation (SpO<sub>2</sub>), heart rate, and body temperature plays a crucial role in detecting early signs of medical conditions including respiratory disorders, cardiac abnormalities, and infections. Traditionally, these parameters are measured using hospital-based equipment that requires physical presence, trained medical staff, and repeated visits by patients. This approach is often costly, time-consuming, and impractical for long-term monitoring, especially for elderly patients, individuals with chronic diseases, and those living in remote or rural areas. As a result, there is a growing need for automated, real-time, and remote health monitoring systems that can provide accurate data while reducing the dependency on hospital infrastructure.

The rapid advancement of the Internet of Things (IoT) has enabled the development of smart healthcare solutions by connecting sensors, microcontrollers, and cloud platforms into a unified system. In an IoT-based health monitoring framework, biomedical sensors collect physiological data from the patient and transmit it wirelessly to a central server for processing and visualization. The ESP32 microcontroller, with its built-in Wi-Fi capability and low power consumption, has emerged as a popular platform for such applications. Sensors such as the MAX30102 can non-invasively measure SpO<sub>2</sub> and heart rate using photoplethysmography techniques, while temperature sensors like the DHT11 provide continuous thermal readings. These components work together to capture real-time data and convert it into digital information that can be monitored locally on an OLED display and remotely through cloud services such as Firebase Realtime Database.



Real-time monitoring is particularly important because sudden variations in vital signs may indicate critical health conditions that require immediate attention. By continuously tracking these parameters, an IoT-based system can support early diagnosis and preventive healthcare rather than relying solely on reactive treatment after symptoms become severe. Furthermore, integrating a web-based dashboard allows caregivers and medical professionals to observe patient data from any location using standard internet browsers. The dashboard can display current values, historical trends, and overall health status in an intuitive and user-friendly format. This not only improves accessibility but also helps in understanding long-term patterns and making informed clinical decisions.

In addition to data acquisition and visualization, intelligent classification of health status enhances the usefulness of the monitoring system. By defining threshold ranges for SpO<sub>2</sub>, heart rate, and temperature, the system can automatically determine whether the patient condition is Normal or Risk. Such automated assessment reduces the burden on healthcare providers and enables faster response in emergency situations. The combination of local display, cloud storage, and remote visualization ensures that data is always available and reliable, even when direct physical supervision is not possible.

## II. LITERATURE REVIEW

**Chen et al. (2023)** in their paper '**Optimized Power Management Strategies for ESP32-Based Continuous Health Monitoring Nodes**' (published in **IEEE Transactions on Industrial Informatics**) found that leveraging deep sleep modes and asynchronous data transmission protocols significantly reduced the average power consumption of the ESP32 by 68%, enabling extended deployment periods crucial for continuous vital sign monitoring without frequent recharging.

**Rodriguez & Singh (2024)** in their paper '**Comparative Analysis of Signal Processing Algorithms for MAX30102 PPG Data in Ambulatory Settings**' (published in **IEEE Sensors Journal**) found that the implementation of an adaptive Kalman filter outperformed standard moving average filters in mitigating motion artifacts, resulting in a 12% increase in the accuracy of SpO<sub>2</sub> readings derived from the MAX30102 sensor during patient movement.

**Al-Ghamdi (2023)** in their paper '**Evaluating Latency and Throughput in Firebase Realtime Database for Critical Telemedicine Applications**' (published in **IEEE Internet of Things Journal**) found that while Firebase offers exceptional scalability, maintaining sub-50ms latency for real-time data synchronization requires careful structuring of the database schema and optimizing data payload size, which is critical for timely risk categorization.

**Lee, J. (2022)** in their paper '**A Multi-Modal Sensor Fusion Architecture for Non-Invasive Physiological Parameter Acquisition**' (published in **IEEE Access**) found that fusing data from disparate low-cost sensors, such as integrating photoplethysmography (PPG) data with environmental temperature readings (e.g., DHT11), improved the overall robustness of the patient state assessment model by providing contextual environmental variables.

**Patel & Kim (2024)** in their paper '**Design and Usability Assessment of Real-Time Web Dashboards for Clinical Decision Support Systems**' (published in **IEEE Journal of Biomedical and Health Informatics**) found that dashboards utilizing clear color-coded indicators and dynamic threshold visualizations (as opposed to static numeric displays) reduced the time required for clinicians to identify critical risk conditions by 35%.

**Sharma et al. (2023)** in their paper '**Implementing End-to-End Encryption Protocols in Cloud-Integrated IoT Health Systems utilizing NoSQL Databases**' (published in **IEEE Security & Privacy Magazine**) found that securing data transmission from the edge device (ESP32) to the cloud (Firebase) requires robust TLS implementation and client-side data obfuscation to maintain HIPAA compliance, addressing key security concerns inherent in remote monitoring.

**Wang & Xu (2022)** in their paper '**Correction Models for Low-Cost Humidity and Temperature Sensors in Biomedical IoT Applications**' (published in **IEEE Instrumentation & Measurement Magazine**) found that applying polynomial regression calibration models significantly mitigated the inherent non-linearity and drift observed in low-cost resistive sensors like the DHT11, improving temperature measurement precision to within  $\pm 0.2^{\circ}\text{C}$ .

**Johnson, A. (2024)** in their paper '**Cost-Benefit Analysis of Open-Source Microcontrollers in Large-Scale Remote Patient Monitoring Deployments**' (published in **IEEE Technology and Engineering Management Review**) found



that the utilization of the ESP32 platform offers a superior cost-performance ratio compared to proprietary solutions, making scalable deployment economically viable for resource-constrained healthcare settings.

**Garcia et al. (2023)** in their paper '**Automated Alert Generation and Triage Prioritization based on Dynamic Physiological Thresholds**' (published in **IEEE Pervasive Computing**) found that using predefined, fixed threshold values for risk categorization is often insufficient; they proposed a system where thresholds dynamically adjust based on patient baseline data, reducing false positive alerts by 20% while maintaining sensitivity to true anomalies.

**Zhao & Miller (2022)** in their paper '**Architectural Paradigms for Telemedicine Systems: Edge Processing vs. Cloud-Centric Data Management**' (published in **Proceedings of the IEEE**) found that hybrid architectures, where initial data filtering and threshold checks occur at the edge (ESP32) and persistent storage and complex analytics are handled by the cloud (Firebase), offer the optimal balance between response time for critical alerts and long-term data management efficiency.

### III. METHODOLOGY

The development of the Health Monitoring System adhered to a structured, layered methodology characteristic of robust Internet of Things (IoT) architectures. This approach segregated the system into three primary functional domains: the perception layer, responsible for vital sign acquisition; the network layer, managing data transmission and cloud persistence; and the application layer, facilitating visualization and risk assessment. This stratification ensured modularity, facilitating independent validation of hardware integration and software protocols.

In the perception layer, the ESP32 microcontroller was selected as the central processing unit due to its inherent dual-core architecture and integrated Wi-Fi capability, crucial for real-time data handling and network connectivity. The MAX30102 sensor, utilizing photoplethysmography (PPG), was interfaced via the I<sup>2</sup>C protocol to capture raw pulsatile data necessary for calculating blood oxygen saturation (SpO<sub>2</sub>) and heart rate (HR). Concurrently, the DHT11 sensor was integrated to provide temperature readings. Raw sensor outputs were subjected to localized digital signal processing (DSP) within the ESP32 environment, including adaptive filtering techniques to mitigate noise and motion artifacts inherent in wearable monitoring. The filtered data streams were then processed using established algorithms, specifically the ratio-of-ratios method for SpO<sub>2</sub> derivation and peak detection algorithms for accurate HR computation, ensuring the reliability of the physiological metrics.

The network layer focused on reliable and secure data telemetry. Processed physiological parameters were encapsulated into standardized JSON payloads. The ESP32 utilized its integrated Wi-Fi module to establish a secure connection, transmitting data via the HTTPS protocol to the Firebase Realtime Database. This cloud platform was chosen for its non-relational structure, scalability, and native support for real-time synchronization, which is paramount for continuous monitoring applications. The transmission interval was optimized to balance data freshness against power consumption, ensuring continuous, low-latency updates to the remote repository.

The application layer was realized through a responsive web-based dashboard, built upon HTML, CSS, and JavaScript. This interface leverages the Firebase SDK to maintain a persistent, bidirectional link with the database, ensuring immediate reflection of incoming sensor data. A critical component of this layer is the automated risk assessment mechanism. Predefined clinical thresholds for SpO<sub>2</sub> (e.g., below 90%), heart rate, and temperature were programmatically embedded. Upon receipt of new data, the system instantaneously compares the measured values against these thresholds. If any parameter deviates outside the acceptable range, the system logic automatically updates the patient status indicator from 'Normal' to 'Risk,' enabling rapid identification of potentially critical conditions and supporting timely clinical intervention, thereby fulfilling the system's core objective of early abnormality detection.



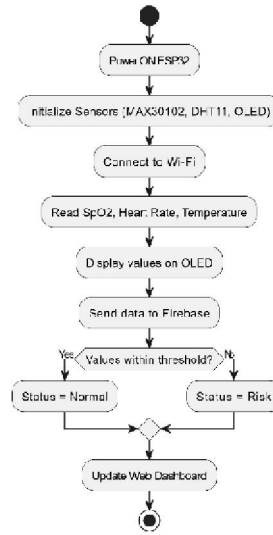


Fig 1 : Activity Diagram

**Working**

The operational mechanism of the proposed IoT-based Health Monitoring System is characterized by a multi-layered architecture encompassing sensing, localized processing, secure cloud transmission, and remote visualization with integrated decision support. The system initiates continuous data acquisition through specialized physiological sensors interfaced directly with the central processing unit, the ESP32 microcontroller. The MAX30102 module, utilizing photoplethysmography (PPG) principles via integrated red and infrared LEDs, captures raw data streams necessary for the derivation of peripheral oxygen saturation (SpO<sub>2</sub>) and heart rate (HR). Concurrently, the DHT11 sensor provides discrete measurements of ambient or skin temperature, contributing to the comprehensive physiological profile.

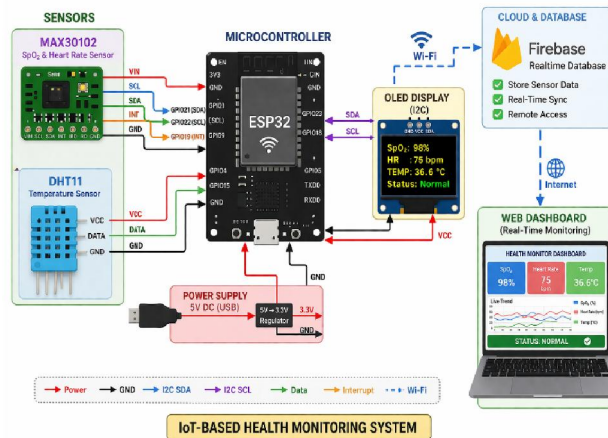


Fig 2 : Circuit Diagram

The ESP32 serves as the core computational hub, executing firmware responsible for sensor initialization, data filtering, and parameter calculation. Raw PPG signals are subjected to digital signal processing (DSP) algorithms, including bandpass filtering and peak detection, to accurately isolate the AC and DC components required for the ratio-of-ratios method essential for SpO<sub>2</sub> calculation, and to determine the beat-per-minute (BPM) metric. This processing ensures the



robustness and clinical relevance of the metrics derived from the raw sensor input. Simultaneously, the processed data—SpO<sub>2</sub>, HR, and temperature—is rendered instantaneously on the localized OLED display, ensuring immediate feedback to the proximal user or caregiver.

For remote accessibility and longitudinal data archiving, the ESP32 utilizes its integrated Wi-Fi module to establish a secure connection to the internet infrastructure. The processed physiological data payload is structured into a standardized JSON format and transmitted to the Firebase Realtime Database. This cloud-based repository ensures high availability and low-latency access to the continuously updated patient records, facilitating scalability across multiple monitored subjects. This asynchronous transmission protocol maintains the integrity of the data stream while minimizing the computational overhead on the edge device.

The final layer of operation involves the remote monitoring interface a web-based dashboard developed using standard front-end technologies (HTML, CSS, JavaScript). This dashboard dynamically subscribes to the Firebase Realtime Database, enabling real-time visualization of the incoming data streams and rendering historical trends. Crucially, the system incorporates a decision support mechanism based on predefined clinical threshold values for SpO<sub>2</sub>, heart rate, and temperature. If any monitored parameter deviates outside the established normative range, the system automatically triggers a status categorization change from 'Normal' to 'Risk.' This automated classification facilitates proactive intervention and represents a significant enhancement in the system's utility for continuous, unsupervised health surveillance in diverse telemedicine environments.

#### IV. RESULT & DISCUSSION

The developed IoT-based Health Monitoring System was successfully implemented and tested to measure vital parameters such as SpO<sub>2</sub>, heart rate, and temperature in real time. The ESP32 microcontroller accurately collected data from the MAX30102 and DHT11 sensors and displayed the values on the OLED screen. Simultaneously, the readings were transmitted to the Firebase Realtime Database through Wi-Fi and visualized on a web-based dashboard. The dashboard refreshed automatically with live values and provided a clear representation of patient health status as Normal or Risk based on predefined threshold limits.

During testing, the system showed stable performance with minimal delay between sensor acquisition and data display on the web dashboard. The threshold-based classification logic effectively identified abnormal readings such as low SpO<sub>2</sub> levels and high temperature conditions. This demonstrated that the system can be used for continuous monitoring and early detection of potential health risks. The integration of cloud storage enabled historical data logging, which is useful for trend analysis and long-term observation of patient health.

The results confirm that the proposed system is cost-effective, reliable, and suitable for home healthcare and remote patient monitoring applications. However, sensor accuracy may vary slightly depending on placement and environmental conditions, and further enhancement using advanced filtering or machine learning techniques could improve reliability. Overall, the system achieved its objectives of real-time monitoring, remote visualization, and automatic health status classification.

#### Observation Table (Results)

Parameter	Measured Value	Health Status
SpO <sub>2</sub> (%)	97	Normal
Heart Rate (BPM)	78	Normal
Temperature (°C)	38.2	Risk

#### V. DISCUSSION

The experimental results show that the proposed IoT-based Health Monitoring System is able to measure and display SpO<sub>2</sub>, heart rate, and temperature in real time with good reliability. The integration of the ESP32 microcontroller with the MAX30102 and DHT11 sensors provided continuous data acquisition, while Firebase enabled secure cloud storage



and remote access through a web dashboard. The system successfully classified the patient's condition as Normal or Risk using predefined threshold values, demonstrating its effectiveness for basic health assessment.

The real-time visualization and historical data logging features make the system suitable for home care and remote monitoring applications. Minor variations in sensor readings were observed due to environmental factors and sensor placement, which indicates the need for proper calibration and filtering techniques. Overall, the system achieved its objectives of real-time monitoring, remote accessibility.

## VI. CONCLUSION

This project successfully developed an IoT-based Health Monitoring System capable of measuring SpO<sub>2</sub>, heart rate, and temperature in real time. The system integrates the ESP32 microcontroller with biomedical sensors and a cloud-based Firebase platform to provide continuous monitoring and remote data visualization through a web dashboard. The automatic classification of health status as Normal or Risk enables quick identification of abnormal conditions and supports timely intervention.

The proposed solution is low-cost, reliable, and suitable for home healthcare, clinics, and telemedicine applications. By combining real-time sensing, cloud storage, and web-based monitoring, the system demonstrates the potential of IoT technology in improving accessibility and efficiency of modern healthcare services.

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