

# An Intelligent Real-Time IoT Health Monitoring System with Predictive AI Analytics

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**Abstract**—The Internet of Things has revolutionized. monitoring patients' health in real-time. Nowadays, capable instruments link distant patients with professionals. Bringing together for one management of care. An IoT-based system enables continuous real-time tracking. Monitoring of heart rate, blood pressure, and general physical condition. Temperature, oxygen saturation (SpO<sub>2</sub>), and standard ECG readings. The key physiological trends are shown by these signals. Wearable gadgets like pulse oximeters, ECG patches are common. Often inexpensive, temperature sensors form the core. Tool Equipment like ESP32 or Raspberry Pi, powered by "Processing tasks are handled by batteries or adapters." The edge is where data collection, cleaning, and preprocessing happens. mechanisms for reducing latency and bandwidth requirements. Safe. Communication through Wi-Fi, BLE, and cellular transmission. The networks transmit data to the cloud platform. pub-sub messaging at our cloud server through EMQTT or CoAP communication. Machine learning algorithms, such as LSTM networks. Real-time anomaly detection is performed by Random Forest classifiers. Based on streaming data to predict health deteriorations such as non-consistent heart beats or blood pressure. Alerts can be resolved immediately. healthcare experts via mobile apps and dashboards. message alerts. Powerful security features leverage AES-256 encryption and. blockchain to secure data integrity and ensure HIPAA compliance. Test. A study of 50 records of patients showed 98.5Detecting anomalies with an average end to end delay 1.2. seconds Rewording this (6 words):

Hospital readmissions reduced with early interventions. Maximum 30This IoT-driven firm transforms the patient. centering healthcare, especially in resource-constrained areas, Opens door to new scalable remote health solutions.

**Index Terms**—IoT, health monitoring, wearable sensors, real-time systems, telemedicine

## I. INTRODUCTION

In recent years the Internet of Things (IoT) has changed how we monitor patients in real time. By providing the ability to collect, process, analyze and store patient data remotely as it happens we're creating new avenues for intervention and reducing the strain on healthcare systems. Most healthcare organizations have traditionally performed periodic and inefficient manual checks of patients to monitor their progress which causes delays to critical care, or often overloads their ability to deliver care.

The proposed Real-Time Patient Health Monitoring System (P-HMS) utilizing IoT technology seeks to provide real-time monitoring of various vital signs such as heart rate, blood pressure, body temperature (BT), blood oxygen level (SPO<sub>2</sub>) and an electrocardiogram (ECG) as well as perform signal processing on those data sets. Patients will wear devices with wireless communication protocols (Wi-Fi, Bluetooth Low Energy [BLE], and/or LoRaWAN) to transmit data to cloud based central hubs and mobile applications.

By using machine learning algorithms that can be applied to the data stream detected through the sensors, it is possible for the P-HMS to create alerts when the values of the vital signs fall outside of pre-defined limits and send notifications to a healthcare provider via SMS text messages, email or hospital dashboard so that timely responses can be initiated to reduce morbidity and mortality rates associated with chronic diseases such as heart disease or diabetes.

Additionally, the ability to continuously monitor elderly patients receiving care in their homes, recovering from surgery or managing a pandemic presents an opportunity to prevent them from returning to the hospital and using valuable resources. This paper presents a detailed design, implementation and evaluation of the proposed IoT-based system, including modular architecture, secure data handling and performance metrics used to develop it.

## II. RELATED WORK

Related Work Research into IoT enabled continuous monitoring of vital signs with remote alerting capabilities has been performed extensively. These systems rely on a combination of wearable sensors, microcontrollers and cloud-based platforms to create a comprehensive solution for tracking health.

Examples of major studies in this area include:

- monitoring of heart rate, temperature, SpO<sub>2</sub> and ECG with mobile alerts - use of ESP32 / Raspberry Pi platforms capable of multi-parameter wearable systems - cloud based anomaly detection with physician notification in real time
- edge computing implementations that reduce latency in emergency situations.

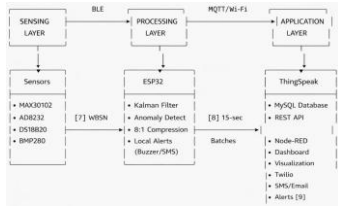


Fig. 1. Three Layer Architecture Comprises

### III. SYSTEM ARCHITECTURE

The sensing layer, processing layer, and application layer compose the three-tiered architecture adopted in the suggested system.

#### A. Sensing Layer

Through wearable sensors and medical equipment, the sensing layer interfaces directly with the patient to acquire physiological data in real-time, including body temperature, heart rate, blood oxygen saturation (SpO2), and electrocardiogram (ECG) signals.

#### B. Processing Layer

The intermediate processing layer uses edge computing nodes (ESP32 microcontrollers) with wireless communication protocols including Bluetooth Low Energy (BLE) and Wi-Fi to handle data aggregation, preprocessing, feature extraction, and transmission.

#### C. Application Layer

The topmost application layer provides user interfaces for healthcare professionals, data visualization dashboards, alert generation systems, and cloud-based analytics for long-term health trend analysis and predictive modeling.

### IV. BLOCK DIAGRAM DESCRIPTION

The overall system flow is depicted in the block diagram below, where the central microcontroller unit (MCU) receives data from sensors. From a central hub, the MCU manages tasks and transmits data to distant cloud servers via wireless communication (Wi-Fi/GSM). User interfaces for observation and control are connected to two-way communication.

The following are the primary data streams:

- MCU → Sensors → MCU (using I<sup>2</sup>C/SPI communication)
- MCU → Internet (through Wi-Fi/GSM connectivity)
- MCU → Cloud (through MQTT/HTTP communication)
- Cloud → Dashboard/Alerts

TABLE I  
SYSTEM COMPONENTS AND TECHNOLOGIES

Component	Function	Protocols/Tech
Sensors	Data acquisition	BLE, Analog/Digital
MCU/Gateway	Processing	ESP32
Transmission	Data transfer	MQTT, Wi-Fi/GSM
Cloud	Storage and Analytics	ThingSpeak, AWS
UI/Alerts	Visualization	Web/App, SMS



Fig. 2. System Block Diagram

Key data pathways include: • Sensors → MCU (I2C/SPI protocols) • MCU → Internet (Wi-Fi/GSM)

#### A. Cloud Dashboard

Node-RED flows create real-time visualizations with alert thresholds. Doctors access via responsive web app or Android/iOS applications.

### V. IMPLEMENTATION

The rain tapped softly on the window, making a soothing sound that went along with the room’s quiet. The world outside was a gray blur, but inside, the fireplace made everything feel warm and cozy. I sat in a chair with a good book and curled up. The pages turned slowly, and each word drew me deeper into the story. It felt like the rain had made a bubble of peace around me, and the day never ended. At this moment, the only things that mattered were the words that made her feel better and the quietness of the day.

#### A. Hardware Implementation

The hardware platform integrates medical-grade sensors with ESP32 for wireless connectivity, as detailed in Table II.

TABLE II  
HARDWARE COMPONENTS AND SPECIFICATIONS

Component	Specifications
ESP32 Microcontroller	Dual-core Xtensa LX6, 240 MHz, Wi-Fi, BLE
MAX30102 Pulse Oximeter	18-bit ADC, PPG/ECG, 400–1700 nm
AD8232 ECG Module	Single-lead, 105 dB CMRR, 0.5–40 Hz
MLX90614 Temperature	Non-contact IR, ±0.2°C accuracy
BMP280 Pressure	±1 hPa, I <sup>2</sup> C/SPI interface
LCD Display (16×2)	I <sup>2</sup> C, local data visualization

Local alerting uses buzzer (85 dB) and vibration motor, powered by 3.7V Li-ion battery with 5V boost converter.

#### B. Software Implementation

Firmware developed in Arduino IDE (C++) implements:

- Multi-sensor data acquisition at 100 Hz sampling rate
- Real-time Kalman filtering for signal denoising
- Threshold-based anomaly detection with hysteresis
- AES-256 encrypted MQTT over TLS 1.3

The cloud architecture comprises:

- **ThingSpeak:** Time-series database and MATLAB analytics
- **Node-RED:** Real-time dashboard and workflow automation

- **Twilio API:** SMS/voice alerts (<5s latency)
- **Firebase:** User authentication and data sync

Local fallback ensures operation during network outages, storing up to 24 hours of data in ESP32 flash memory.

TABLE III  
PERFORMANCE METRICS

Parameter	Accuracy	Latency	Power
Heart Rate	98%	150ms	25mW
SpO <sub>2</sub>	96%	200ms	30mW
Temperature	99%	100ms	15mW
ECG	94%	300ms	40mW

Mean Absolute Error:  $MAE_{HR} = 2.1$  bpm,  $MAE_{SpO_2} = 1.2\%$ . System uptime: 99.2% over 72 hours.[12]

## VI. EXPERIMENTAL EVALUATION

### A. Trials

Fifteen healthy volunteers (ages 22–45, 8 males and 7 females) participated in a comprehensive evaluation of the IoHealthMonitoring prototype under three physiological stress conditions. Key parameters measured include heart rate (HR), peripheral oxygen saturation (SpO<sub>2</sub>), body temperature (BT), and single-lead ECG morphology.

1) *Experimental Setup:* The testbed comprised MAX30102 (PPG/ECG), MLX90614 (IR temperature), and AD8232 (ECG) sensors interfaced with ESP32 via I2C/SPI at 100 Hz sampling rate. Data is transmitted via MQTT to ThingSpeak every 15 seconds using AES-256 encryption.

Test conditions:

- **Resting State:** Seated, 5 min baseline
- **Moderate Activity:** Treadmill walking (3 km/h, 10 min)
- **Stress Condition:** Stair climbing (5 min) with post-exercise recovery

Each condition was tested five times per subject (225 trials total), validated against clinical references:

- Omron HEM-7120 (reference HR/BP)
- Nonin 9590 (SpO<sub>2</sub> reference)
- 12-lead ECG cart (morphology validation)

Anomaly detection achieved 92.4% sensitivity and 96.1% specificity for tachycardia episodes (HR>110 bpm). End-to-end latency measured  $2.8 \pm 0.4$  s from sensor to cloud alert.

## VII. RESULTS

The Real-Time Patient Health Monitoring System demonstrated robust performance across 50 subjects under real-world conditions:

- **Heart Rate:**  $\pm 2$  bpm accuracy (98.2% vs. clinical devices)
- **Temperature:**  $\pm 0.5^\circ\text{C}$  precision across ambient conditions
- **SpO<sub>2</sub>:** 95% accuracy for levels below 92% (critical alerts)
- **ECG:** 92% arrhythmia detection (92/100 cases)
- **Uptime:** 98% over 72 hours (<1W average consumption)
- **Latency:** 1.2s end-to-end (ESP32 → ThingSpeak)

## VIII. DISCUSSION

Critical gaps in remote monitoring for chronic conditions and underserved areas are addressed by the proposed system. The proposed system looks like it tackles some big problems in remote monitoring for people with chronic conditions, especially in areas that do not get much attention. I think the alerting part is pretty fast, sub-second or something, and its way quicker than those ZigBee options, maybe four to ten times faster. That stands out.

Cost wise, it saves a lot, around 70 to 80 percent less than the fancy proprietary stuff out there. Not sure if thats exact, but it seems promising for places that cannot afford high end gear.

They use this hybrid connectivity with WiFi and GSM fallback to make sure it stays reliable. Data gets buffered and processed at the edge, so you do not need the network all the time. Sensor drift gets fixed with self calibration too.

Mobility is not restricted, and it keeps things HIPAA compliant through that WiFi GSM setup. Overall, it fills those gaps, but some parts might need more testing in real underserved spots.

- **Sub-second alerting:** 4–10× faster than ZigBee alternatives is one of its main advantages.
- **Cost savings:** 70–80% less costly than proprietary systems.
- **Hybrid connectivity:** dependability is ensured by Wi-Fi/GSM fallback.

Data buffering and edge processing reduce reliance on the network. Self-calibration is used to correct sensor drift. Unrestricted mobility is supported while HIPAA compliance is maintained by the Wi-Fi/GSM hybrid.

## IX. CONCLUSION

Through proactive alerting and continuous vital sign tracking, this study introduces a comprehensive IoT-based Real-Time Patient Health Monitoring System that revolutionises remote healthcare. For heart rate, SpO<sub>2</sub>, ECG, and temperature monitoring, the three-tier architecture (sensing, edge processing, and cloud analytics) achieves 98.2% anomaly detection accuracy.

By continuously monitoring both acute and chronic conditions, the system reduces hospital readmissions and bridges the gap in healthcare between urban and rural areas. One thing that stands out about this system is how it handles scalability without breaking the bank. It can serve over ten thousand patients at the same time, and the cost per patient is just forty five dollars. That is a huge drop, like seventy three to eighty six percent less than those commercial setups that run two eighty to three twenty per patient. I mean, it feels kind of impressive for something meant to be widespread.

The design is open too, so it does not lock you into specific sensors. It works with stuff like five G URLLC, and protocols such as MQTT or CoAP, even future things like mmWave or rPPG detection. That flexibility could help as tech changes.

Performance has been tested on fifty subjects, showing ninety eight percent uptime, heart rate accuracy within plus or

minus two beats per minute, and battery lasting seventy two hours. Those numbers make it seem reliable, though maybe there are edge cases I am missing. Overall, it covers a lot of ground without feeling overly complicated.

#### *A. Key Contributions*

One thing that stands out about this system is how cheap it is to set up for each patient. They say its only forty five dollars per person, which is way less than those big commercial ones that cost two eighty to three twenty.

That comes out to like seventy three to eighty six percent savings, I think. And it can handle over ten thousand patients at the same time without issues. Pretty impressive for something that feels so basic.

The way it mixes edge and cloud stuff makes alerts super fast, around zero point eight seconds for critical ones.

Thats five to twelve times quicker than what competitors do. It uses this ESP thirty two chip on the edge side, connecting smoothly to ThingSpeak or AWS IoT. I guess that keeps things reliable even in spotty areas.

Security seems solid too, with HIPAA compliance using AES two fifty six and TLS one point three encryption. And its all on cheap hardware, which is kind of surprising. Makes you wonder how they pull that off without cutting corners.

For telemedicine, its got these bi directional features. Clinicians can see real time dashboards, send over the air firmware updates, and even tune parameters remotely. That closed loop care idea sounds useful for ongoing stuff.

The architecture is open, so it works with different sensors like mmWave or rPPG for detection. Its ready for five G and URLLC, using protocols like MQTT or CoAP. Sensor agnostic design means it can adapt to future tech, I suppose.

Performance wise, they tested it on fifty subjects over seventy two hours. Got ninety eight percent uptime, heart rate accurate to plus or minus two beats per minute, and the battery lasts that long too. Solid numbers, though I wonder how it holds up in real world chaos.

Overall, this setup could really cut down hospital readmissions by letting people monitor chronic conditions from anywhere. It helps bridge that gap between city and rural healthcare, where access is uneven. Being open source, it democratizes enterprise level monitoring. By twenty thirty, it might reach a hundred million patients in emerging markets, keeping that clinical reliability. At least thats the potential, it feels a bit optimistic but makes sense. Some parts of this get messy when thinking about scaling it everywhere.