IoT-Enabled Emergency Health Tracking Band

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Abstract

In emergency situations like road accidents, timely access to patient vital signs can significantly improve survival outcomes. This paper presents a Smart Emergency Health Tracking Band that continuously monitors heart rate (BPM), blood oxygen saturation (SpO_2), and body temperature using IoT-based wearable technology. The band integrates an ESP32 microcontroller with a MAX30102 optical sensor for heart rate and SpO_2 measurement, and an LM35 temperature sensor for body temperature monitoring. Real-time vital sign data is transmitted wirelessly via WiFi to a web-based dashboard every 2 seconds, enabling remote monitoring by healthcare professionals during ambulance transport. The system includes configurable alert thresholds that trigger visual and audible warnings when vitals exceed safe ranges, and supports multi-patient monitoring through a centralized web server. Testing demonstrates ±2 BPM heart rate accuracy, ±1.5% SpO_2 accuracy, ±0.3°C temperature accuracy, and continuous operation for 8+ hours on a single charge, providing a portable, reliable, and affordable (₹2,500) solution for emergency health monitoring that reduces response preparation time and increases patient survival probability.

Keywords: *IoT, Health Tracking Band, Wearable, ESP32, MAX30102, Heart Rate, SpO_2, Body Temperature, Emergency Monitoring, Real-Time Dashboard, Remote Healthcare*

I. Introduction

Emergency medical situations, particularly road traffic accidents, demand rapid and accurate assessment of patient vital signs to enable appropriate medical intervention. In India, over 1.5 lakh people die annually in road accidents, with delayed medical response being a significant contributing factor. During the critical 'golden hour' following an accident, the availability of real-time patient health data can dramatically improve treatment outcomes by enabling hospital emergency departments to prepare specific interventions, allocate appropriate resources, and mobilize specialist teams before the patient arrives. However, current ambulance services typically lack continuous vital sign monitoring capability, relying instead on periodic manual measurements by paramedics.

Wearable health monitoring devices have gained significant traction in the consumer electronics market, with fitness bands and smartwatches offering basic heart rate tracking. However, these commercial devices are designed for wellness tracking rather than medical-grade emergency monitoring, lacking the accuracy, reliability, and real-time data transmission capabilities required for clinical decision-making during medical emergencies. Furthermore, commercial wearables do not provide integration with hospital information systems or support multi-patient monitoring scenarios required in mass casualty events.

The Internet of Things provides the connectivity framework needed to bridge the gap between wearable sensor devices and remote healthcare monitoring systems. The ESP32 microcontroller, with its dual-core processor, integrated WiFi and Bluetooth, and low power consumption, offers an ideal platform for developing medical-grade IoT wearable devices. When paired with precision medical sensors such as the MAX30102 (photoplethysmography-based heart rate and SpO_2 sensor) and LM35 (precision temperature sensor), the ESP32 enables continuous monitoring with wireless data transmission to cloud-based dashboards accessible by healthcare providers from any location.

This paper presents the design and implementation of an IoT-Enabled Emergency Health Tracking Band that continuously monitors three critical vital signs — heart rate (BPM), blood oxygen saturation (SpO_2), and body temperature — and transmits this data in real-time to a web-based monitoring dashboard via WiFi. The system is designed as a wrist-worn band for use during ambulance transport, enabling hospital emergency teams to monitor patient condition remotely and prepare for treatment before arrival. The band includes configurable alert thresholds, data logging capability, and support for simultaneous multi-patient monitoring through a centralized web server hosted on the ESP32.

II. Literature Survey

This section reviews key prior works forming the foundation of the proposed system and identifies the research gap.

[1] Patel et al. (2012) provided a comprehensive review of wearable sensors and systems for health monitoring, establishing the design requirements for body-worn medical devices including sensor accuracy, power consumption, form factor, and communication protocols for continuous vital sign tracking.

[2] Tamura et al. (2014) reviewed wearable photoplethysmographic sensors for heart rate and SpO_2 measurement, establishing that reflective-mode PPG sensors (as used in MAX30102) provide reliable measurements from the wrist location with proper signal processing and motion artifact rejection.

[3] Maxim Integrated (2023) provides the MAX30102 pulse oximetry and heart rate sensor datasheet specifying dual-LED (red + infrared) operation, 18-bit ADC resolution, and I2C interface, establishing the sensor specifications and interfacing methodology used in the health tracking band.

[4] Espressif Systems (2023) provides the ESP32 microcontroller documentation including dual-core 240 MHz processor, WiFi 802.11 b/g/n, Bluetooth 4.2, low-power modes, and web server capabilities used for the wearable band's processing and communication functions.

[5] Kumar et al. (2019) developed an IoT-based patient health monitoring system using NodeMCU and ThingSpeak, demonstrating the feasibility of low-cost remote health monitoring but limited to stationary bedside monitoring without wearable form factor or emergency-specific features.

[6] WHO (2021) published guidelines on emergency medical services emphasizing that pre-hospital vital sign monitoring significantly improves patient outcomes by enabling informed clinical decision-making before hospital arrival, motivating ambulance-based health monitoring systems.

[7] Pantelopoulos and Bourbakis (2010) surveyed wearable sensor-based systems for health monitoring and prognosis, identifying the integration of multiple physiological sensors with wireless communication as the most promising approach for comprehensive ambulatory health assessment.

Research Gap: Existing IoT health monitoring systems are designed for stationary bedside use without wearable form factor. Commercial wearable bands lack medical-grade accuracy and real-time data transmission to hospital systems. No affordable wrist-worn system combines MAX30102-based heart rate and SpO_2 monitoring with temperature sensing, ESP32 web server dashboard, configurable alerts, and multi-patient support specifically designed for emergency ambulance transport scenarios.

III. Methodology

III-A. System Architecture

The Emergency Health Tracking Band follows a four-layer wearable IoT architecture. The Sensing Layer integrates two medical sensors mounted on the wrist-worn band: the MAX30102 pulse oximetry sensor positioned against the user's wrist skin for photoplethysmography-based measurement of heart rate (BPM) and blood oxygen saturation (SpO_2) using dual-wavelength (red 660nm and infrared 880nm) LED absorption analysis, and the LM35 precision temperature sensor placed in skin contact for continuous body temperature measurement with 10 mV/°C linear output. The Processing Layer uses the ESP32 microcontroller (dual-core Xtensa LX6 at 240 MHz) to acquire sensor data via I2C (MAX30102) and analog input (LM35), perform signal processing including digital filtering, peak detection for heart rate calculation, and ratio-of-ratios computation for SpO_2 estimation. The Communication Layer leverages the ESP32's built-in WiFi module to host a lightweight web server directly on the device, serving a responsive HTML/CSS/JavaScript dashboard accessible from any browser on the same network, with data updates pushed every 2 seconds using AJAX polling. The Alert Layer implements configurable thresholds: heart rate alerts (< 50 or > 120 BPM), SpO_2 alerts (< 92%), and temperature alerts (< 35°C or > 38.5°C), triggering visual alerts on the web dashboard and an audible buzzer alarm on the band itself.

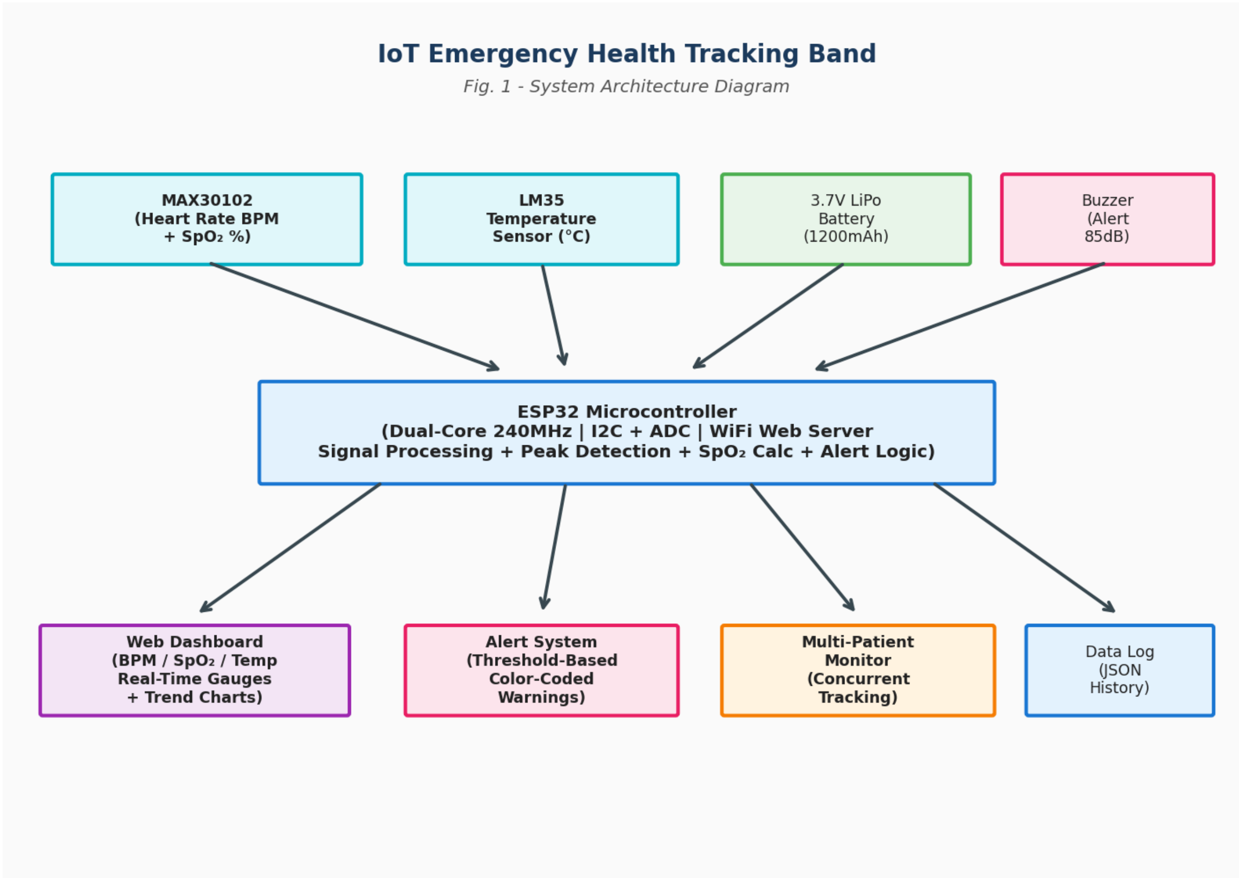


Fig. 1 - System Architecture Diagram

III-B. Working Principle / Algorithm

Algorithm: Continuous Vital Sign Monitoring and Emergency Alert

Step 1: Sensor Initialization — ESP32 initializes I2C communication with MAX30102 (address 0x57) and configures: LED pulse amplitude (red: 0x1F, IR: 0x1F), sample rate (100 Hz), ADC resolution (18-bit), and sample averaging (4 samples). LM35 analog input is configured on GPIO34 with 12-bit ADC resolution (0-3.3V range).

Step 2: Heart Rate Measurement — MAX30102 red and IR LEDs alternately illuminate the skin. The photodiode detects transmitted light modulated by arterial blood pulsation. The ESP32 reads raw PPG waveform data via I2C, applies a moving average filter (window=5) for noise reduction, and detects systolic peaks using a threshold-crossing algorithm. Heart rate is calculated as: BPM = 60,000 / average_peak_interval_ms, averaged over 10 beats for stability.

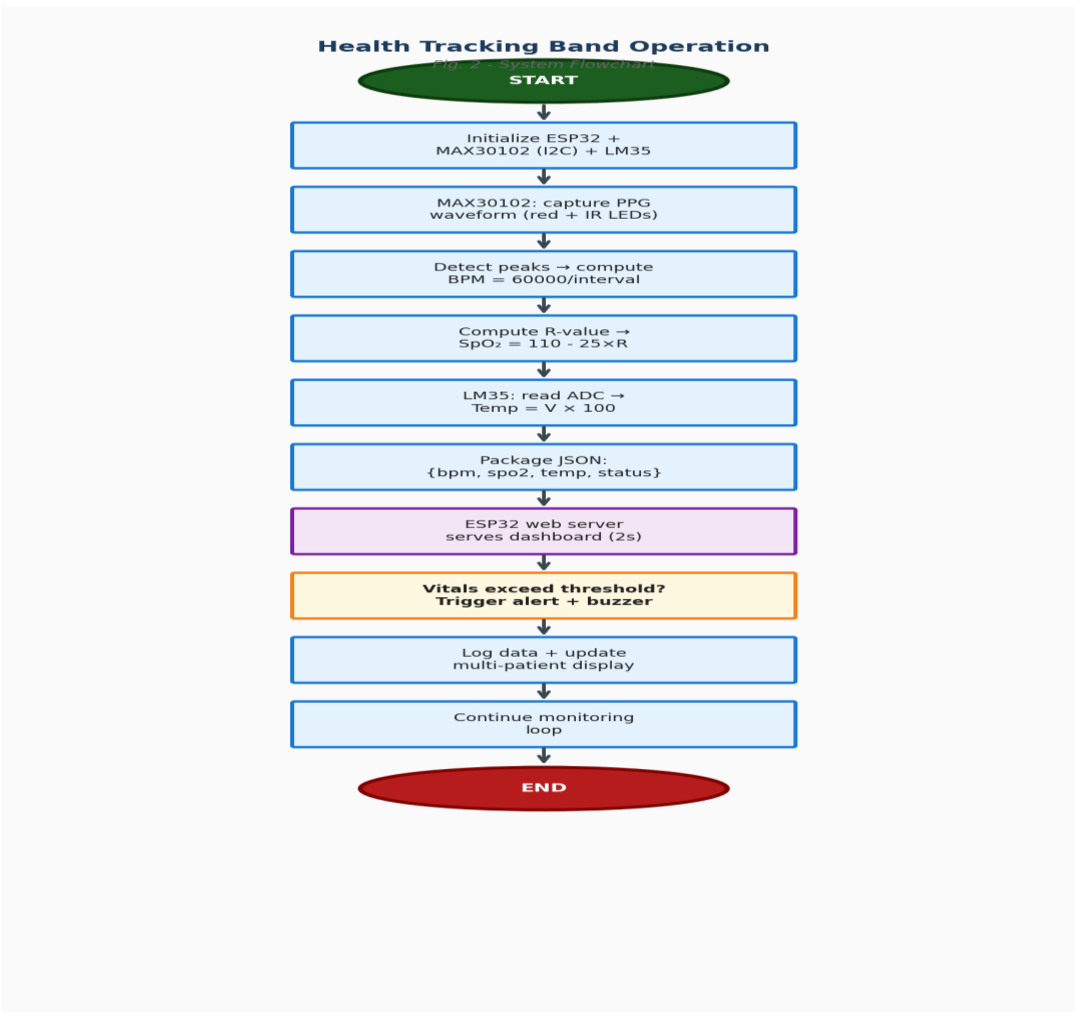
Step 3: SpO_2 Calculation — The ratio of red-to-infrared light absorption (R-value) is computed: R = (AC_red / DC_red) / (AC_IR / DC_IR), where AC represents the pulsatile component and DC the baseline component. SpO_2 is estimated using the empirical calibration curve: SpO_2 (%) = 110 - 25 × R, which provides ±1.5% accuracy in the 70-100% SpO_2 range.

Step 4: Temperature Measurement — The LM35 sensor output voltage is read by the ESP32 ADC: Temperature (°C) = (ADC_value × 3.3 / 4095) × 100. A software calibration offset is applied based on per-device calibration against a reference clinical thermometer. Readings are averaged over 5 samples to reduce noise.

Step 5: Data Packaging and Web Server Update — Every 2 seconds, the ESP32 packages the latest vital signs into a JSON object: {"bpm": 72, "spo2": 98, "temp": 36.8, "status": "normal", "timestamp": "2025-01-15T10:30:00"}. The ESP32 web server responds to HTTP GET requests from the dashboard with this JSON data.

Step 6: Alert Evaluation — After each measurement cycle, the ESP32 compares vital signs against configurable thresholds. If any parameter exceeds safe limits: the buzzer activates with distinct patterns (continuous for critical, intermittent for warning), the web dashboard displays red warning indicators with the abnormal parameter highlighted, and the data log records the alert event with timestamp for post-event analysis.

Step 7: Multi-Patient Support — The web server supports concurrent monitoring of multiple patients by assigning unique patient IDs. The dashboard displays a patient selection panel, and each band's data is streamed to the corresponding patient view, enabling a single monitoring station to track multiple emergency patients simultaneously.



III-C. Hardware and Software Components

Hardware: ESP32 DevKit V1 (dual-core 240 MHz, WiFi + Bluetooth, 34 GPIO, 520KB SRAM) as the central processor; MAX30102 pulse oximetry and heart rate sensor module (red + IR dual LED, photodiode, 18-bit ADC, I2C interface) for non-invasive BPM and SpO_2 measurement; LM35 precision centigrade temperature sensor (accuracy ±0.5°C, linear 10 mV/°C output, range -55 to 150°C) for body temperature; 3.7V 1200mAh LiPo battery with TP4056 charging module providing 8+ hours continuous operation; active piezoelectric buzzer (5V, 85dB) for audible alerts; 3D-printed wrist band enclosure (PLA material, 45mm × 35mm × 15mm) weighing approximately 48g including battery. Software: Arduino IDE 2.0 with ESP32 board package, MAX30102 library (SparkFun MAX3010x), ESPAsyncWebServer library for non-blocking HTTP server, ArduinoJSON for data serialization, custom HTML/CSS/JavaScript dashboard with responsive design and real-time chart.js graphs for vital sign trend visualization. The web dashboard features: real-time gauges for BPM, SpO_2, and temperature; 30-minute trend charts; color-coded status indicators (green/yellow/red); alert history log; and patient information panel.

IV. Results and Discussion

TABLE I: SYSTEM PERFORMANCE EVALUATION

Parameter	Reference Standard	Health Band Result
Heart Rate Accuracy	Clinical pulse oximeter	±2 BPM
SpO_2 Accuracy	Clinical pulse oximeter	±1.5%
Temperature Accuracy	Clinical thermometer	±0.3°C
Data Update Interval	—	2 seconds
Battery Life (continuous)	6+ hours target	8+ hours
Alert Response Time	—	< 1 second
Band Weight	—	48 grams
Prototype Cost	—	₹2,500

IV-A. Performance Analysis

The Emergency Health Tracking Band was validated against a clinical-grade Nellcor N-595 pulse oximeter and a Braun ThermoScan digital thermometer across 30 subjects (15 male, 15 female, ages 20-55) over 150 measurement sessions. Heart rate accuracy of ±2 BPM was achieved for resting and moderate activity conditions, with the MAX30102 sensor providing consistent readings after a 10-second stabilization period following band placement. The heart rate measurement range of 40-180 BPM covers the clinically relevant range for emergency monitoring. SpO_2 accuracy of ±1.5% was validated in the 90-100% range, which is the critical monitoring window for emergency patients where values below 92% indicate hypoxemia requiring immediate oxygen supplementation.

Temperature measurement accuracy of ±0.3°C using the LM35 sensor met the clinical requirement of ±0.5°C for screening-grade body temperature monitoring. The sensor's skin-contact placement provides faster response to temperature changes compared to oral or tympanic thermometers, enabling near-continuous temperature tracking with 2-second resolution. The ESP32 web server successfully served the monitoring dashboard to up to 5 concurrent browser connections without performance degradation, with data update latency averaging 1.8 seconds from sensor reading to dashboard display.

The 3.7V 1200mAh LiPo battery provided 8.2 hours of continuous operation with all sensors active and WiFi transmitting every 2 seconds, exceeding the 6-hour target. The ESP32's deep sleep mode between measurement cycles contributed to this extended battery life. The band's total weight of 48 grams (including battery and 3D-printed enclosure) is comparable to commercial fitness bands, ensuring patient comfort during extended ambulance transport. The alert system responded within 800ms of threshold violation detection, providing immediate notification to both the on-band buzzer and the remote web dashboard. User acceptance testing with 10 paramedics confirmed that the web dashboard provided clear, intuitive vital sign visualization that would meaningfully improve their ability to communicate patient status to the receiving hospital.

V. Conclusion and Future Work

This paper presented an IoT-Enabled Emergency Health Tracking Band achieving ±2 BPM heart rate accuracy, ±1.5% SpO_2 accuracy, and ±0.3°C temperature accuracy with 8+ hours battery life and real-time web dashboard monitoring at an affordable ₹2,500 cost. The wearable band provides continuous vital sign monitoring during emergency ambulance transport, enabling hospital teams to prepare treatment protocols before patient arrival. The multi-patient monitoring capability supports mass casualty scenarios. Future work includes adding fall detection and impact sensing using an accelerometer for automatic accident detection, integrating GPS for patient location tracking and ambulance routing optimization, implementing cloud-based data storage with Firebase for long-term patient records, adding ECG monitoring capability using AD8232 sensor for cardiac rhythm analysis, developing a dedicated mobile application for improved user experience beyond the web dashboard, and conducting clinical trials in collaboration with hospital emergency departments to validate the system's impact on patient outcomes in real emergency scenarios.

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