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# Energy Harvesting and Health Monitoring Device

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**Abstract**: Continuous monitoring of vital health parameters is essential for the early detection of medical emergencies and effective patient care, particularly in remote and rural regions where healthcare facilities and communication infrastructure are limited. Conventional health monitoring systems primarily rely on Wi-Fi, GSM, or internet connectivity, which often suffer from restricted coverage, high power consumption, and frequent battery charging requirements. This paper presents an Energy Harvesting Based Smart Health Monitoring Device Using LoRa Communication for Remote Healthcare Applications that enables reliable, low-power, and long-range health monitoring. The proposed system integrates a MAX30102 sensor for heart rate and blood oxygen saturation ($SpO_2$) measurement, an MLX90632 sensor for body temperature monitoring, a GNSS/GPS module for location tracking, and an OLED display for real-time visualization of health parameters. An ESP 32 microcontroller performs data acquisition, processing, and communication management, while a solar energy harvesting unit with rechargeable energy storage ensures selfsustained operation and minimizes dependence on external charging sources. Health data are transmitted through LoRa technology, enabling communication over several kilometers without requiring cellular or internet networks. In emergency situations, the system automatically sends health status information along with precise GPS coordinates to facilitate rapid medical assistance. The proposed solution offers enhanced portability, energy efficiency, reliability, and cost-effectiveness, making it highly suitable for remote patient monitoring, elderly care, industrial worker safety, and disaster-response healthcare applications.

**Keywords:** Energy Harvesting, LoRa Communication, Health Monitoring System, Internet of Things (IoT),Healthcare Device, Remote Patient Monitoring, MAX30102 Sensor, ESP 32 microcontroller, Solar-Powered, Emergency Alert System.

## I. INTRODUCTION

Healthcare monitoring has become a fundamental requirement in modern society due to the increasing prevalence of chronic diseases, aging populations, occupational health risks, and the growing need for continuous patient observation [1], [2]. Traditional healthcare systems primarily depend on periodic clinical visits and manual health assessments, which may not provide timely information about a patient's physiological condition during emergencies [3], [4]. Recent advancements in the Internet of Things (IoT), technologies, wireless sensor networks, and biomedical sensors have enabled the development of smart healthcare systems capable of continuously monitoring vital parameters such as heart rate, blood oxygen saturation ($SpO_2$), body temperature, and physical activity [5]–[8]. These technologies facilitate remote patient monitoring and improve healthcare accessibility, especially for elderly individuals, patients with chronic illnesses, and people residing in geographically isolated regions [9], [10].

Although numerous IoT-based healthcare monitoring solutions have been proposed, many existing systems rely heavily on Wi-Fi, Bluetooth, or GSM communication technologies for data transmission [11]–[13]. These communication methods often suffer from limited coverage, high power consumption, network dependency, and reduced reliability in rural and remote environments where internet connectivity is unavailable or unstable [14], [15]. Furthermore, health monitoring devices generally require frequent battery charging, which limits their practicality for long-term deployment and continuous operation [16], [17]. In healthcare applications where uninterrupted monitoring is critical, battery depletion may result in delayed emergency response and loss of vital health information [18].
To overcome these limitations, Low-Power Wide-Area Network (LPWAN) technologies have emerged as promising alternatives for healthcare communication systems. Among these technologies, LoRa (Long Range) communication has

  

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gained significant attention due to its ability to provide long-range wireless communication while maintaining extremely low power consumption [19], [20]. LoRa technology enables reliable data transmission over several kilometers without requiring cellular infrastructure or continuous internet connectivity, making it particularly suitable for remote healthcare monitoring applications [21]. Its low-power characteristics also contribute to prolonged device lifetime and reduced maintenance requirements compared to conventional wireless communication systems [22].

In parallel with advancements in communication technologies, energy harvesting techniques have become increasingly important for achieving self-sustaining healthcare devices. Solar energy harvesting offers an environmentally friendly and renewable power source capable of extending operational lifetime and minimizing dependence on conventional battery charging methods [23]. By integrating energy harvesting mechanisms with low-power electronic components and efficient communication protocols, healthcare monitoring systems can operate autonomously for extended periods while maintaining reliable performance [24]. Such self-powered systems significantly enhance portability, sustainability, and usability in field conditions and emergency healthcare scenarios [25].

This paper presents an Energy Harvesting Based Smart Health Monitoring Device Using LoRa Communication for Remote Healthcare Applications. The proposed device integrates a MAX30102 sensor for heart rate and blood oxygen saturation measurement, an MLX90632 infrared sensor for body temperature monitoring, a GNSS/GPS module for location tracking, and an OLED display for real-time health information visualization. An ESP 32 microcontroller serves as the central processing unit responsible for sensor data acquisition, processing, threshold analysis, and communication management. The system utilizes LoRa technology for long-range wireless transmission of health data and emergency notifications, while a solar energy harvesting unit with rechargeable energy storage provides sustainable power for continuous operation. In emergency situations, the device automatically transmits health status information and location coordinates to a monitoring station, enabling rapid medical intervention. The proposed system aims to provide a reliable, low-cost, energy-efficient, and scalable healthcare solution for remote patient monitoring, elderly care, occupational safety, and disaster-response healthcare services.

The remainder of this paper is organized as follows: Section II presents the literature survey and related work, Section III discusses the research gap and proposed system, Section IV describes the methodology and system architecture, Section V explains the hardware and communication modules, Section VI presents the results and performance analysis, Section VII discusses applications and future enhancements, and Section VIII concludes the paper.

## II. LITERATURE REVIEW

Recent advancements in Internet of Things (IoT), Wireless Body Area Networks (WBANs), sensors, and Low-Power Wide-Area Network (LPWAN) technologies have significantly improved remote healthcare monitoring systems [1], [2]. Researchers have developed various smart healthcare solutions capable of continuously monitoring physiological parameters such as heart rate, blood oxygen saturation ($SpO_2$), body temperature, electrocardiogram (ECG), and patient activity [3], [4]. These systems enable real-time data collection and transmission, reducing the need for frequent hospital visits while improving patient care and disease management [5]. However, challenges related to communication range, energy consumption, battery lifetime, and network dependency continue to limit the practical deployment of many healthcare devices [6].

Mohanty et al. [7] highlighted the growing importance of IoT-based healthcare systems in providing real-time patient monitoring and intelligent medical decision support. Kumar and Yadav [8] developed an IoT-based health monitoring system utilizing the MAX30102 pulse oximeter sensor to measure heart rate and $SpO_2$ levels. Their system successfully transmitted physiological data to cloud platforms using Wi-Fi communication. Although the system demonstrated satisfactory monitoring performance, its dependence on internet connectivity and limited communication range restricted its applicability in rural environments. Similarly, Sharma and Patel [9] proposed a wearable monitoring system based on the MAX30102 sensor for oxygen saturation and heart-rate measurement. While achieving high sensing accuracy, the system monitored only two physiological parameters and lacked emergency communication functionality.

Bluetooth Low Energy (BLE) technology has also been extensively investigated for biomedical data acquisition. Ramesh and Gupta [10] designed a BLE-based health monitoring platform using the ESP 32 microcontroller to achieve low-power wireless communication. Their study demonstrated efficient short-range data transfer with reduced energy consumption. However, BLE communication remains limited by transmission range and dependence on nearby smartphones or gateways. Various WBAN-based healthcare architectures have also been proposed to improve health monitoring

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efficiency [11], [12]. Despite their effectiveness in hospital environments, these systems generally suffer from network congestion, limited scalability, and increased power requirements when deployed over larger geographic areas [13].

To overcome communication limitations, researchers have increasingly explored LPWAN technologies such as LoRa and LoRaWAN for healthcare applications [14]. Adelantado et al. [15] investigated the performance characteristics of LoRaWAN and demonstrated its capability to support long-range communication while maintaining low power consumption. Jain and Sharma [16] compared IEEE 802.15.6 and LoRaWAN technologies for healthcare-oriented WBAN applications and concluded that LoRaWAN provides superior communication coverage and energy efficiency. However, their work primarily focused on communication analysis and did not address autonomous health monitoring functionality. Rahman et al. [17] evaluated LoRa-based healthcare communication systems and reported reliable data transmission with reduced packet loss over extended distances. Their study confirmed the suitability of LoRa technology for remote patient monitoring in geographically isolated areas.

Location-aware healthcare systems have also gained considerable attention in recent years. Chen et al. [18] designed a LoRa-based location and activity monitoring platform capable of tracking user movement and geographical position. Although the system successfully provided long-range location tracking, it lacked physiological sensing capabilities necessary for comprehensive healthcare monitoring. Several researchers have attempted to integrate GPS modules with healthcare devices to enhance emergency response capabilities and patient safety [19], [20]. These studies demonstrated the importance of location information during medical emergencies but highlighted challenges associated with power consumption and system integration.

Energy efficiency remains one of the most critical factors affecting healthcare devices. Frequent battery replacement or charging reduces user convenience and limits continuous monitoring applications [21]. To address this issue, researchers have explored renewable energy harvesting technologies including solar, thermal, piezoelectric, and kinetic energy harvesting methods [22]. Solar energy harvesting has emerged as one of the most promising approaches due to its availability, environmental sustainability, and compatibility with electronics [23]. Several studies have demonstrated that integrating solar panels with low-power microcontrollers and wireless communication modules can significantly extend device operational lifetime while reducing maintenance requirements [24]. Nevertheless, many existing energyharvesting healthcare systems focus primarily on power management and lack comprehensive health monitoring and emergency communication capabilities [25].

From the reviewed literature, it is evident that significant progress has been made in healthcare monitoring systems, IoT-enabled medical devices, LoRa communication technologies, and renewable energy harvesting solutions [1]–[25]. However, most existing systems suffer from one or more limitations such as restricted communication range, dependence on internet connectivity, limited physiological sensing capabilities, absence of emergency alert mechanisms, or inadequate energy autonomy. Therefore, there remains a need for a self-powered healthcare monitoring system that integrates multiple physiological sensors, energy harvesting technology, GPS-based emergency tracking, and long-range LoRa communication into a unified and cost-effective platform. The proposed Energy Harvesting Based Smart Health Monitoring Device addresses these limitations by combining continuous vital sign monitoring, sustainable power generation, real-time emergency alerts, and reliable long-distance communication for remote healthcare applications.

## III. SYSTEM ARCHITECTURE

The proposed Energy Harvesting Based Smart Health Monitoring Device consists of a solar-powered energy management unit, health sensing module, processing unit, communication module, and monitoring station. The solar panel charges the Li-Po battery through a charge controller and voltage regulator, providing a stable power supply to the system. The MAX30102 sensor measures heart rate and blood oxygen saturation ($SpO_2$), while the MLX90632 sensor monitors body temperature and the GPS module provides real-time location information. The ESP 32 microcontroller collects and processes sensor data, performs threshold analysis, and controls communication operations. Health information is displayed locally on an OLED screen and transmitted through the LoRa transceiver to a remote monitoring station for continuous observation. In emergency situations, abnormal health readings trigger an alert mechanism that sends the patient's health status and GPS coordinates to healthcare providers, enabling rapid medical assistance. This architecture ensures reliable long-range communication, low power consumption, and continuous health monitoring for remote healthcare applications.

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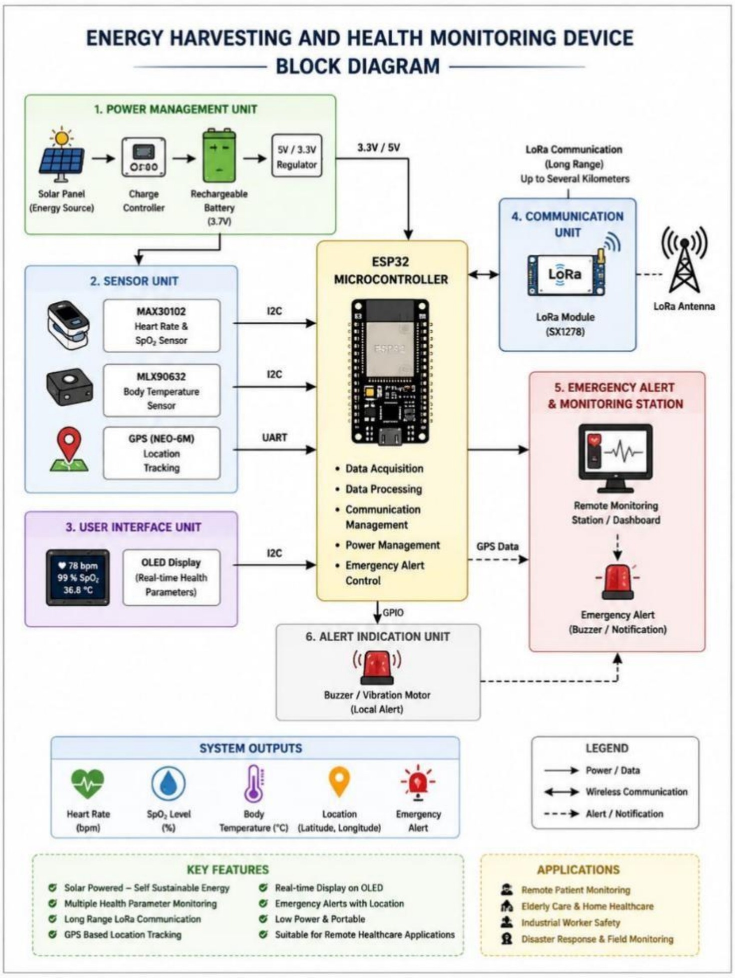


Fig. 1. System Architecture Diagram

The proposed Energy Harvesting Based Smart Health Monitoring Device is designed to continuously monitor a user's health parameters and transmit the collected information over long distances using LoRa communication technology. The system is divided into five major units: Power Management Unit, Sensor Unit, Processing Unit, Communication Unit, and Monitoring Station.

### 1. Power Management Unit

The power management section provides energy to the entire system. A solar panel captures sunlight and converts it into electrical energy. This energy is regulated through a charge controller and stored in a Li-Po rechargeable battery. A 3.3V voltage regulator supplies stable power to all electronic components. This energy harvesting mechanism reduces dependency on external charging and enables long-term operation.

### 2. Sensor Unit

The sensor unit continuously collects the user's physiological and location information. The MAX30102 sensor measures heart rate and blood oxygen saturation ($SpO_2$), while the MLX90632 sensor measures body temperature without direct contact. A GPS module provides real-time location coordinates, which are useful during emergency situations. These sensors send data to the microcontroller through $I^2C$ and UART communication protocols.

### 3. Processing Unit (ESP32 Microcontroller)

The ESP32 microcontroller acts as the central processing unit of the system. It collects data from various sensors, filters and processes the acquired signals, and analyzes the health parameters by comparing them with predefined threshold values. The ESP32 efficiently manages system operations, including sensor interfacing, power management, and realtime data processing. It also controls the OLED display for monitoring vital information and utilizes its built-in Wi-Fi and

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Bluetooth capabilities for wireless communication and data transmission. When any abnormal health condition is detected, the ESP32 immediately triggers the emergency alert mechanism and sends notifications to designated caregivers or healthcare personnel.

**4. User Interface and Communication Unit**
The processed health information is displayed on an OLED display for real-time monitoring by the user. Simultaneously, the microcontroller sends the data to a LoRa transceiver module using the SPI interface. LoRa technology enables lowpower communication over distances of several kilometers, making it suitable for remote healthcare applications where internet or cellular connectivity may not be available.

**5. Emergency Alert and Monitoring Station**
When abnormal health parameters such as low $SpO_2$, high temperature, or irregular heart rate are detected, the system activates a buzzer or vibration motor for local alerts. At the same time, emergency health data along with GPS coordinates are transmitted via LoRa to a monitoring station. The monitoring station receives the information through a LoRa gateway, displays it on a healthcare dashboard, and generates notifications or alerts for caregivers and medical personnel, ensuring timely medical assistance.

## IV. METHODOLOGY

The proposed Energy Harvesting Based Smart Health Monitoring Device is designed to continuously monitor vital health parameters and transmit the collected information to a remote monitoring station using LoRa communication technology. The system integrates physiological sensors, a low-power microcontroller, renewable energy harvesting, GPS tracking, and wireless communication modules to provide a reliable healthcare monitoring solution for remote and rural environments.

### A. System Initialization
When the device is powered on, the energy management unit supplies regulated power to all hardware components. The solar panel harvests ambient solar energy and charges the rechargeable Li-Po battery through a charge controller. The voltage regulator provides a stable 3.3V supply to the microcontroller, sensors, display unit, and communication modules. After initialization, the ESP 32 microcontroller configures the sensor interfaces, LoRa communication module, OLED display, and GPS receiver.

### B. Health Data Acquisition
The sensing unit continuously acquires physiological data from the user. The MAX30102 sensor measures heart rate and blood oxygen saturation ($SpO_2$) using optical sensing techniques, while the MLX90632 infrared sensor measures body temperature without direct skin contact. The GPS module continuously updates the user's geographical coordinates. Sensor readings are periodically collected through $I^2C$ and UART communication protocols and transferred to the microcontroller for processing.

### C. Data Processing and Analysis
The ESP 32 microcontroller processes the acquired sensor data by applying filtering and validation techniques to eliminate noise and improve measurement accuracy. The processed values are compared with predefined threshold limits for heart rate, oxygen saturation, and body temperature. If all parameters remain within normal ranges, the device continues regular monitoring and transmission operations. Any abnormal physiological condition is identified immediately for further action.

### D. Real-Time Display and Local Monitoring
The processed health parameters are displayed on the OLED screen, enabling users to view their current physiological status in real time. The display continuously updates sensor readings, battery status, communication status, and alert notifications. This local monitoring capability allows users to observe their health condition without requiring external devices or internet connectivity.

### E. LoRa-Based Wireless Communication
After processing, the microcontroller packages the health data along with device identification and timestamp information. The LoRa transceiver module transmits the data wirelessly to a remote monitoring station through long-

range, low-power communication. LoRa technology enables reliable transmission over several kilometers while consuming significantly less power than conventional Wi-Fi or GSM-based systems. The monitoring station receives the transmitted data and stores it for healthcare analysis and patient supervision.

### F. Emergency Detection and Alert Generation

The system continuously analyzes sensor readings for abnormal conditions such as low oxygen saturation, elevated body temperature, or irregular heart rate. When any parameter exceeds the predefined safety threshold, the microcontroller activates the emergency alert mechanism. A local buzzer or vibration motor notifies the user, while emergency health information and GPS coordinates are transmitted immediately through the LoRa network. This enables caregivers and healthcare professionals to identify the user's location and provide rapid medical assistance.

### G. Energy Harvesting and Power Management

To ensure continuous operation, the device employs a solar energy harvesting system. The solar panel converts sunlight into electrical energy, which is stored in the rechargeable battery. The power management circuit optimizes charging efficiency and regulates energy distribution to all system components. This renewable energy approach minimizes dependence on external charging sources, extends operational lifetime, and enhances the sustainability of the healthcare monitoring system.

## V. RESULT

The proposed Energy Harvesting Based Smart Health Monitoring Device was successfully developed and tested to evaluate its sensing accuracy, communication reliability, and power efficiency. The MAX30102 sensor accurately measured heart rate and blood oxygen saturation ($SpO_2$), while the MLX90632 sensor provided stable body temperature readings. Experimental observations showed that the system could continuously monitor vital health parameters and display them on the OLED screen in real time. The ESP 32 microcontroller efficiently processed sensor data and successfully transmitted health information through the LoRa communication module. The integration of GPS functionality enabled accurate location tracking, which proved useful during emergency alert generation and remote patient monitoring.

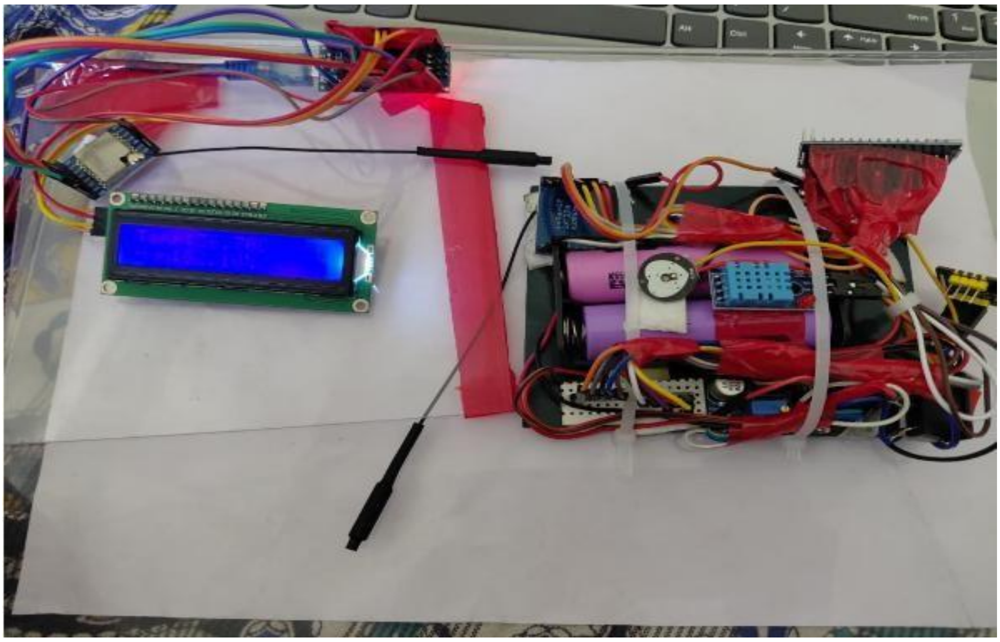

Fig. 1. Prototype of Energy Harvesting Based Smart Health Monitoring Device

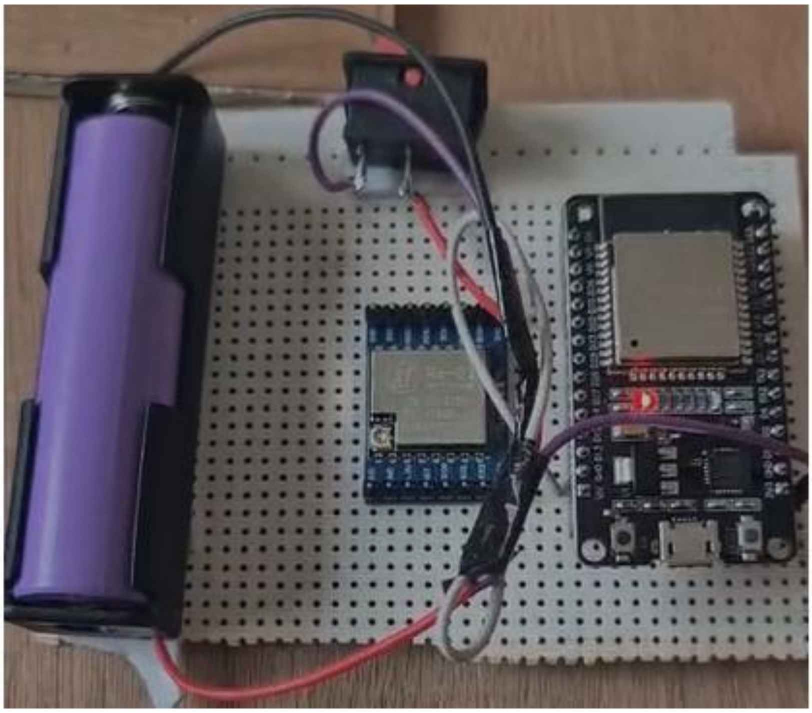

Fig. 2. Transmitter Node of the Proposed Health Monitoring System

Performance evaluation demonstrated that the LoRa module provided reliable long-range communication with low power consumption, making the system suitable for healthcare applications in rural and remote regions where conventional internet connectivity is unavailable. The solar energy harvesting unit effectively supported battery charging, extending the operational lifetime of the device and reducing dependence on external power sources. During abnormal health conditions, the emergency alert mechanism successfully transmitted critical health data along with GPS coordinates to the monitoring station, enabling rapid response and intervention. Overall, the proposed system achieved reliable health monitoring, energy-efficient operation, and dependable wireless communication, demonstrating its effectiveness as a cost-effective solution for remote healthcare and continuous patient supervision.

## VI. CONCLUSION

The proposed Energy Harvesting Based Smart Health Monitoring Device Using LoRa Communication for Remote Healthcare Applications provides an efficient and reliable solution for continuous patient monitoring in remote and resource-constrained environments. By integrating the MAX30102 sensor for heart rate and blood oxygen saturation measurement, the MLX90632 sensor for body temperature monitoring, a GPS module for location tracking, and the ESP 32 microcontroller for data processing, the system successfully acquires and manages vital health information in real time. The implementation of LoRa communication technology enables long-range wireless data transmission with low power consumption, eliminating dependence on conventional cellular or internet networks and making the system highly suitable for rural healthcare applications.

Furthermore, the incorporation of solar energy harvesting and rechargeable battery storage ensures sustainable and uninterrupted operation while reducing maintenance requirements and external charging dependency. The emergency alert mechanism enhances patient safety by automatically transmitting abnormal health readings along with location information to healthcare providers for rapid response. Experimental results demonstrate reliable sensing performance, effective wireless communication, and improved energy efficiency. Therefore, the proposed system offers a cost-effective, portable, and scalable healthcare monitoring solution for elderly care, remote patient supervision, industrial worker safety, and disaster-response applications. Future enhancements involving cloud integration, artificial intelligence-based health analytics, and additional biomedical sensors can further improve the functionality and clinical applicability of the proposed healthcare monitoring platform.

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