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IoT-Based Hospital Assist Robot Using ESP32 for Real-Time Hazard Detection and Environmental Monitoring Applications

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Abstract

The increasing complexity of healthcare environments and the need for continuous patient safety monitoring have accelerated the adoption of intelligent hospital automation systems, with global healthcare IoT solutions expected to exceed 300 billion USD and hospital-related safety incidents contributing to significant risks for patients and staff annually. Additionally, hazards such as gas leakage, fire outbreaks, and environmental instability in hospitals require real-time monitoring and rapid response systems to prevent critical situations. Traditional hospital monitoring systems rely heavily on manual inspection and fixed monitoring devices, which may fail to detect sudden hazards in time and lack mobility and real-time communication capabilities. Furthermore, conventional systems do not integrate multi-sensor monitoring, robotic assistance, or remote accessibility, reducing their effectiveness in dynamic healthcare environments. To address these challenges, the proposed Hospital Assist Robot utilizes the ESP32 microcontroller to develop an intelligent and mobile healthcare monitoring solution. The system integrates fire, gas, smoke, and vibration sensors to continuously monitor environmental conditions, while an ESP32-CAM enables real-time video surveillance for remote observation. The robot is equipped with a mobility mechanism to navigate across hospital areas, enhancing coverage and monitoring efficiency. Upon detecting abnormal conditions, the system triggers buzzer alerts and displays warning messages on an LCD to notify staff immediately. IoT integration allows real-time data transmission to cloud platforms for remote monitoring and analysis. This smart robotic system improves hospital safety, enables rapid emergency response, reduces manual effort, and supports the development of intelligent and connected healthcare infrastructures.

Keywords: Fire Detection, Gas Sensor, Hospital Automation, Internet of Things, Robotics Automation, Smart Healthcare System, Vibration Sensor, Wireless Monitoring

1. Introduction

The increasing complexity of healthcare environments and the need for continuous patient safety monitoring have significantly accelerated the adoption of intelligent hospital automation systems. Global healthcare IoT solutions are expected to exceed 300 billion USD [1], reflecting a major shift toward connected and smart medical infrastructures. Hospitals face numerous safety risks, including gas leaks, fire outbreaks, and environmental instability, which can endanger both patients and medical staff [2]. In critical environments such as hospital wards, intensive care units (ICUs), laboratories, and medical storage facilities, there is a strong demand for systems that provide real-time monitoring, automated alert generation, and rapid response capabilities to ensure safety and operational efficiency.

Traditional hospital monitoring systems rely primarily on manual inspection and fixed

monitoring devices [3]. While these methods provide basic safety measures, they are often insufficient in detecting sudden hazards in dynamic healthcare environments. Fixed systems have limited coverage and cannot adapt to changing conditions across different hospital areas [4]. Additionally, conventional approaches lack integration of multiple sensors, real-time communication, and mobility, making it difficult to monitor large or complex facilities effectively [5]. The absence of remote monitoring and intelligent analytics further reduces the ability to respond quickly to emergencies and maintain a safe environment.

In real-time scenarios, these limitations lead to several critical challenges that can compromise hospital safety and patient care. Hazards such as gas leakage, smoke, fire, or structural vibrations may not be detected promptly, increasing the risk of severe incidents [6]. Delayed alerts and lack of continuous monitoring can hinder timely response by medical staff. Furthermore, limited coverage of fixed systems may leave certain areas unmonitored, especially in large hospital infrastructures [7]. The absence of automated and mobile solutions increases dependency on human supervision, adding to workload and reducing efficiency. These challenges highlight the need for an intelligent [8], IoT-based robotic monitoring system capable of continuous environmental sensing, real-time video surveillance, autonomous mobility, and instant alert generation, ensuring enhanced safety, faster response, and improved healthcare infrastructure management.

2. Literature Survey

Irshad et al. [9] proposed a narrative review on the integration of robotics in healthcare management, analyzing applications such as patient assistance, monitoring, and surgical support. Leigh et al. [10] proposed a person tracking and following system using two-dimensional laser scanners for mobile robots. Koide et al. [11] proposed a person identification system for following robots using color, height, and gait features. Duong et al. [12] proposed a human gait tracking system using two-dimensional Light Detection and Ranging (LiDAR) sensors for both normal individuals and walker users. Rudenko et al. [13] proposed a human-robot navigation dataset containing accurate motion trajectories for improving tracking and navigation systems.

Munaro et al. [14] proposed a fast Red Green Blue-Depth (RGB-D) based people tracking system for service robots using depth and color information. Jafari et al. [15] proposed a real-time RGB-D based people detection and tracking system for mobile robots and wearable cameras. Koide et al. [16] proposed a people tracking and re-identification system using face recognition in RGB-D camera networks.

Ye et al. [17] proposed a vision-based human tracking control system for a wheeled inverted pendulum robot. Oswal et al. [18] proposed a line-following robot system for factory environments using simulation tools to evaluate navigation performance. Latif et al. [19] proposed a microcontroller-based line follower robot using ATmega32A for path tracking applications. Portmann et al. [20] proposed a people detection and tracking system using aerial thermal imaging for monitoring applications.

3. Proposed System

Figure 1 illustrates the architecture of the Hospital Assist Robot, an intelligent safety and monitoring system built around the ESP32. The system integrates multiple environmental sensors such as fire, gas, smoke, and vibration sensors to continuously monitor hospital conditions. An ESP32-CAM module provides real-time visual monitoring, while a battery powers the entire robotic system for mobility. The ESP32 processes all sensor data and controls output devices including an LCD display, buzzer alerts, robotic movement

system, and IoT connectivity. This system ensures real-time hazard detection, automated alerts, and efficient monitoring across hospital environments.

Step 1: Power Supply (Battery Unit): The system is powered by a battery, enabling portability and continuous operation of the robot within hospital premises.

Step 2: Environmental Monitoring Sensors: Sensors such as fire, gas, smoke, and vibration continuously monitor environmental conditions. These sensors detect hazards like fire outbreaks, gas leaks, smoke accumulation, and abnormal vibrations.

Step 3: Visual Monitoring using ESP32-CAM: The ESP32-CAM captures real-time images or video of the surroundings, enabling remote visual inspection and verification of detected hazards.

Step 4: Data Processing by ESP32: The ESP32 collects and processes all sensor data, compares it with predefined thresholds, and determines whether a hazardous condition exists.

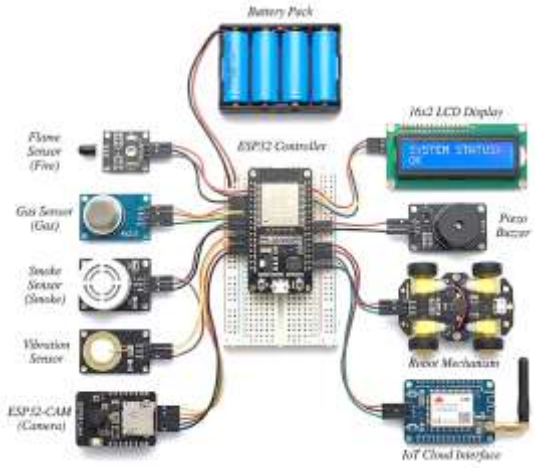


Figure 1. Hospital Assist Robot – ESP32-Based Smart Safety Monitoring System.

Step 5: LCD Display Output: The LCD displays real-time system status, sensor readings, and alert messages, allowing local monitoring by hospital staff.

Step 6: Buzzer Alert System: When abnormal conditions are detected, the buzzer is activated to provide immediate audible alerts, ensuring quick response from nearby personnel.

Step 7: Robot Mobility System: The robotic platform enables the system to move across different hospital areas such as wards, corridors, and storage rooms, ensuring wide-area monitoring.

Step 8: IoT-Based Remote Monitoring: The ESP32 transmits real-time sensor data and alerts to a cloud platform via IoT, enabling hospital administrators to monitor conditions remotely and receive instant notifications.

3.1 Working Procedure

The proposed system as shown in Figure 2, Hospital Assist Robot, is designed to improve safety and monitoring in hospital environments by integrating sensors, robotics, and IoT technologies. Hospitals contain many sensitive areas such as patient wards, medical laboratories, and equipment storage rooms where environmental hazards like fire, gas leakage, smoke accumulation, or abnormal vibrations may occur. Continuous monitoring of these conditions is essential to prevent accidents and ensure the safety of patients and medical staff. The proposed system provides an intelligent solution that can monitor environmental conditions automatically and generate alerts whenever abnormal situations occur.

The system is built around the ESP32 microcontroller, which acts as the central controller responsible for processing sensor inputs and controlling output devices. Various sensors such as fire sensor, gas sensor, smoke sensor, and vibration sensor are connected to the ESP32 to monitor different environmental parameters within the hospital. These sensors continuously collect data from the surroundings and send it to the ESP32 for analysis.

When any sensor detects an abnormal condition, such as the presence of fire, harmful gas leakage, smoke, or excessive vibration, the ESP32 processes the sensor data and activates

alert mechanisms. A buzzer is triggered to provide an audible warning so that nearby staff can quickly respond to the situation. At the same time, an LCD display shows the warning message or system status information.

To enhance monitoring capabilities, the system integrates an ESP-CAM module that captures real-time images or video of the monitored area. This allows hospital administrators or monitoring personnel to observe conditions remotely and verify emergency situations visually.

The system also includes a robot movement mechanism, which allows the robot to move within the hospital environment. This mobility enables the system to monitor multiple locations such as corridors, patient wards, and equipment rooms.

Additionally, the system integrates IoT technology, which enables the transmission of sensor data to remote monitoring platforms through internet connectivity. This allows hospital administrators to monitor environmental conditions in real time and receive alerts even when they are not physically present in the hospital.

By combining sensor-based monitoring, robotic mobility, camera surveillance, and IoT communication, the proposed system provides a comprehensive solution for improving hospital safety and monitoring efficiency.

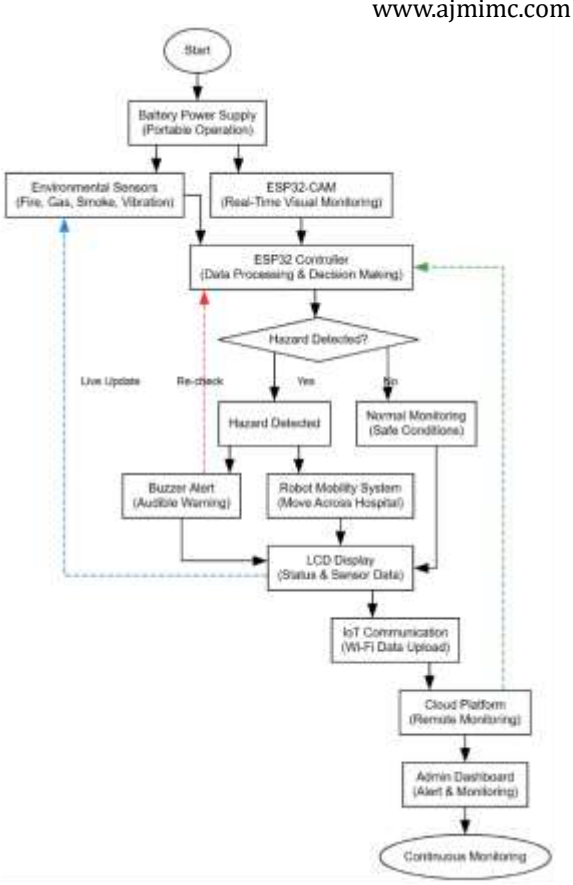


Figure 2. Proposed Flowchart.

Figure 3 illustrates the circuit diagram of an IoT-based hospital assist robot designed to support healthcare environments through automated monitoring and assistance. The system is powered by a regulated power supply unit consisting of a step-down transformer, bridge rectifier, filter capacitors, and a 7805-voltage regulator to provide a stable +5V output. The ESP32 microcontroller acts as the central control unit, interfacing with fire and gas sensors to detect hazardous conditions, a smoke sensor for air quality monitoring, and a vibration sensor for movement or emergency detection. A robotic module enables mobility for assisting tasks within hospital premises. An IoT camera module provides real-time surveillance and remote monitoring of patients and surroundings. The system also includes a 16×2 LCD to display status updates and alerts, while a buzzer generates audible warnings during emergencies. This integrated design enhances patient safety, supports healthcare staff, and

enables efficient real-time monitoring in smart hospital environments.

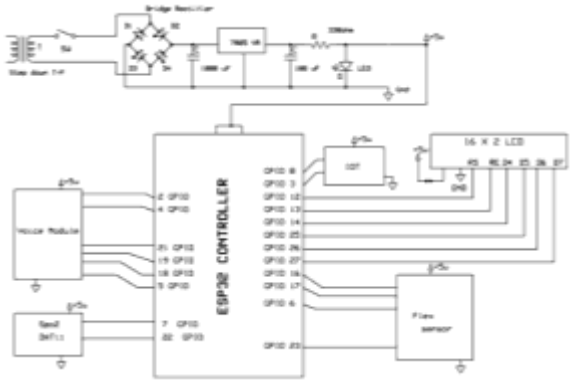


Figure 3. Circuit Diagram of IoT-Based Hospital Assist Robot Using ESP32.

4. Results and Discussion

The Fig. 4 shows an IoT-based hospital robot prototype built using an ESP32-CAM module. The robot includes multiple sensors such as a smoke sensor, gas sensor, and fall detection sensor for patient safety and environment monitoring. All components are connected with wires on a base platform, forming a working model. The system is designed to monitor hazards and assist in hospital environments with real-time data and alerts**.**

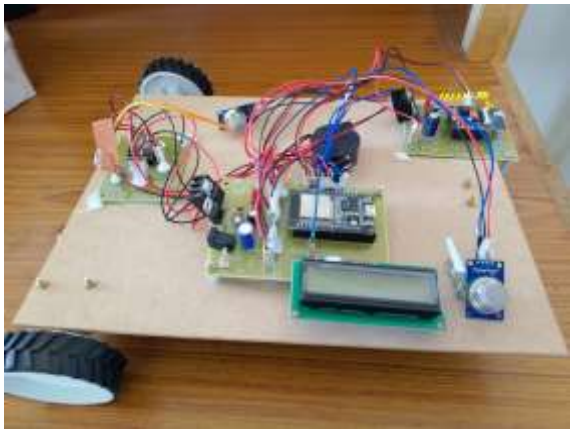


Fig. 4: Enhanced robot prototype with integrated sensing and control modules

The Fig. 5 shows an IoT-based hospital assistant robot prototype built using an ESP32 module. A 16x2 LCD display shows the message “Hospital Assist Robot.” The setup includes a gas sensor module and connected electronic components mounted on a base board. The system is designed to detect gases and assist in monitoring hospital environments.



Fig. 5: LCD displaying hospital assist robot status

The Fig. 6 displays a data monitoring table from the IoT system. It shows sensor readings such as fire status, gas detection, smoke levels, vibration (fall detection), and date/time records. The table helps in tracking real-time data and alerts for safety monitoring in hospital environments

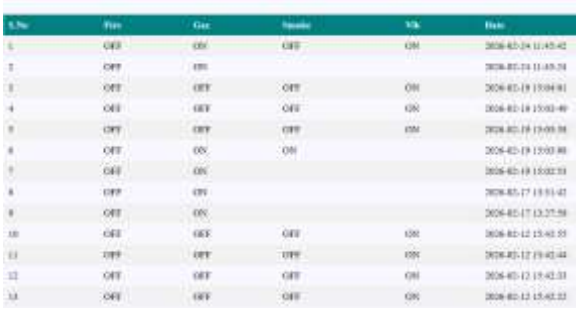


Fig. 6: Dashboard showing real-time fire, gas, smoke, and vibration data logs

5. Conclusion

The proposed Hospital Assist Robot provides an advanced and intelligent solution for enhancing safety and monitoring in modern healthcare environments by integrating mobility, multi-sensor detection, and IoT connectivity. By utilizing the ESP32 microcontroller along with fire, gas, smoke,

and vibration sensors, the system ensures continuous monitoring of critical environmental parameters, enabling early detection of hazards such as leaks, fires, or structural disturbances. The inclusion of an ESP32-CAM allows real-time video surveillance, while the robot's mobility enhances coverage across different hospital areas, overcoming the limitations of fixed monitoring systems. Immediate alerts through buzzer notifications and LCD display ensure rapid response from medical staff, while IoT integration facilitates remote monitoring, data analysis, and centralized control. This system reduces dependency on manual inspection, improves operational efficiency, and enhances patient and staff safety. Finally, it contributes to the development of smart, automated, and responsive healthcare infrastructures capable of handling dynamic hospital environments effectively.

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