

IoT-Enabled Asset Tracking Framework for Hospitals

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Abstract—Efficient tracking and management of medical equipment are critical for improving resource utilization, minimizing capital expenditure, and reducing operational delays in healthcare facilities. Traditional manual inventory procedures are labor-intensive, highly subjective, and prone to human error, making it difficult to maintain accurate and up-to-date equipment location records across multi-room clinical environments. To address these challenges, this paper presents a comprehensive Internet of Things (IoT)-enabled framework for hospital asset intelligence and tracking using Radio Frequency Identification (RFID) technology. The prototype integrates an ESP32 microcontroller and an EM-18 RFID reader module to identify tagged medical assets, utilizing designated room-switching transponder cards to dynamically record and update locations across specific hospital zones namely Reception, Pharmacy, Store room, ICU-01, General Ward-01, Operation Theatre, and General Ward-02. A robust software backend built with Python FastAPI and MongoDB manages asset information, telemetry, and tracking records, while an interactive React-based dashboard provides a multi-tenant command interface for viewing equipment details, live vital signs (battery health and core temperature), and real-time spatial layouts. Furthermore, the system autonomously enforces configured tracking rules, including geofence-based unauthorized room transfer detection and proactive 30-day warranty expiration notifications based on stored lifecycle data. Comprehensive workflow testing and experimental evaluation were conducted to verify asset identification, room-level tracking accuracy, and instant alert generation.

Index Terms—Asset tracking, Internet of Things (IoT), RFID, ESP32, hospital equipment management, warranty notifications.

I. INTRODUCTION

Medical equipment ranging from mobile infusion pumps and diagnostic kits to critical care monitors represents a vital capital investment in modern healthcare facilities. Managing these assets across

complex, multi-room hospital campuses is challenging. Misplaced equipment leads to delayed emergency responses, increased capital expenditure due to unnecessary repurchasing, and compliance vulnerabilities during regulatory audits. Each medical asset exhibits unique characteristics, including purchase value, manufacturer details, warranty expiration dates, and department assignments. Reliable identification and tracking of these items are essential for clinical resource allocation, ward planning, and quality control.

Traditional approaches to asset tracking rely primarily on manual record-keeping and visual audits performed by biomedical staff. While manual audits can be effective in controlled environments, they are inherently subjective, labor-intensive, and susceptible to human error. Furthermore, such methods become inefficient and slow when applied to fast-paced hospital operations or extensive inventory datasets.

The rapid advancement of artificial intelligence, computer vision, and IoT technologies has enabled the development of automated systems capable of performing real-time tracking with high reliability. In particular, microcontroller-based IoT sensing and RFID transponder integration have emerged as powerful tools for monitoring physical assets.

In this study, an IoT-based framework is proposed for automated hospital asset tracking and geofencing using an ESP32 microcontroller integrated with RFID scanning hardware. The system is paired with a Python FastAPI backend and a React dashboard. The primary objective is to design and evaluate a system capable of real-time room tracking, unauthorized movement detection, and proactive warranty monitoring. By automating these workflows, the proposed solution reduces reliance on manual checks and provides a practical decision-support tool for healthcare administrators.

II. RELATED WORK

Internet of Things (IoT) technologies are increasingly being explored for healthcare applications, including equipment monitoring, resource management, and connected medical systems. Rehman et al. [1] reviewed developments in healthcare IoT, including security considerations and implementation challenges. Gopichand et al. [2] examined the use of IoT sensor devices for healthcare system management. Research has also investigated different approaches to identifying and tracking hospital assets. Andalusia et al. [3] presented an object-detection approach for hospital assets using YOLOv8. Asabe et al. [4] discussed an IoT-based storage system for managing medical resources, while Eneh et al. [5] examined the use of IoT-embedded technologies for tracking biomedical equipment.

RFID-based identification and real-time locating systems are also relevant to healthcare asset management. Profetto et al. [6] reviewed RFID applications in healthcare, while Bazo et al. [7] surveyed real-time location systems in healthcare environments. Overmann et al. [8] reviewed the use of real-time locating systems to improve healthcare delivery. Abugabah et al. [9] discussed challenges associated with implementing RFID technology in the healthcare sector, and Boulos and Berry [10] provided an overview of real-time locating systems and their healthcare applications.

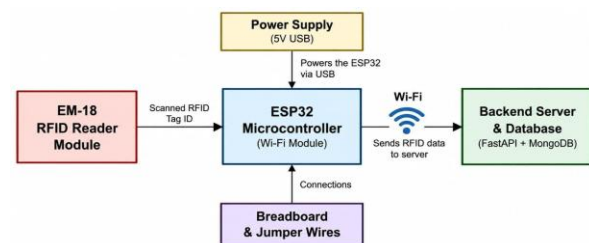
These studies demonstrate the relevance of IoT, RFID, and locating technologies to healthcare resource management. The suitability of each approach depends on factors such as the required location detail, infrastructure, cost, and operating environment. The framework presented in this paper focuses on RFID-based asset identification, room-level location recording, asset alerts, and warranty notifications.

Basic workflow testing was conducted to check the operation of the prototype. Quantitative performance evaluation and testing in a larger hospital environment remain areas for future work.

III. RESEARCH METHODOLOGY

The proposed IoT-enabled hospital asset tracking framework is designed to identify tagged medical equipment, maintain room-level asset records, and provide alerts and warranty notifications. The prototype uses RFID-based identification with an ESP32 microcontroller and an EM-18 RFID reader. The system architecture consists of the asset identification hardware, a software backend, a database, and a user interface, where these software components are implemented in the prototype.

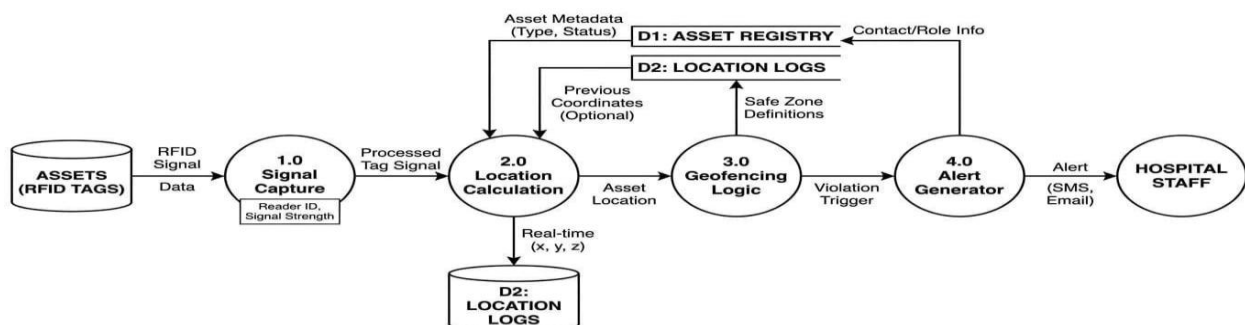
Hardware Architecture



The hardware prototype uses an ESP32 microcontroller connected to an EM-18 RFID reader. The RFID reader reads the identifier stored in an RFID tag, and the ESP32 processes or forwards the scanned identifier to the software system. The asset identifier is used to retrieve the corresponding asset record. The ESP32 provides the hardware interface between the RFID reader and the software application.

System Data Flow and Processing

LEVEL 1 DFD: RFID ASSET TRACKING SYSTEM



The server-side workflow follows the Level 1 Data Flow Diagram (DFD) layout to process tags and manage security alerts:

1.Signal Capture (Process 1.0): The system reads the raw RFID signal from the asset tags and captures reader details.

2.Location Calculation (Process 2.0): The backend receives the tag data, cross-references it with D1: Asset Registry to fetch metadata (like equipment type and status), and logs the position into D2: Location Logs.

3.Geofencing Logic (Process 3.0): The calculated asset location is checked against predefined safe zone boundaries. If an asset moves outside its designated area or room without permission, it triggers a violation event.

4.Alert Generator (Process 4.0): Once a violation is triggered, the system pulls contact and role info from the asset registry and sends an immediate alert notification to the Hospital Staff.

IV. EXPERIMENTAL EVALUATION

The prototype was subjected to basic workflow testing to check the operation of RFID-based asset identification and tracking. The evaluation focused on whether the system could process an asset-tracking event and maintain the corresponding recorded asset information.

A. Testing Setup

The prototype uses an ESP32 microcontroller and an EM-18 RFID reader for RFID-based asset identification. The software components used in the test were those implemented in the prototype. The basic workflow was tested to check the operation of the asset-tracking process.

B. Basic Tracking Workflow

During the test, an RFID-tagged asset was presented to the RFID reader. The system processed the scanned identifier and used it to identify the associated asset record. The tracking workflow was checked to confirm that the system could process the asset information as intended.

The prototype also includes functionality for tracking-related alerts and warranty notifications. These functions should be reported as experimentally evaluated only if separate tests were conducted to verify their operation. The current basic workflow test does not establish numerical tracking accuracy, alert response time, or long-term reliability.

C. Evaluation Scope

The initial evaluation establishes a basic functional check of the asset-tracking workflow. A more detailed evaluation should include repeated asset scans, room-identification tests, correct and incorrect tracking scenarios, and warranty-notification test cases. The results should record the number of attempts, successful outcomes, and measured response times. Quantitative performance evaluation remains future work until these measurements are collected. No numerical accuracy or response-time result is claimed in this paper.

V. CONCLUSION

This paper presented an IoT-enabled framework for hospital asset tracking using RFID technology. The prototype uses an ESP32 microcontroller and an EM-18 RFID reader to identify tagged assets and supports asset tracking, tracking-related alerts, and warranty notifications. Basic workflow testing was conducted to check the operation of the asset-tracking process.

The prototype provides a foundation for organizing hospital asset records and improving access to recorded equipment information. However, the basic testing conducted so far does not establish quantitative tracking accuracy, room-detection reliability, notification response time, or performance in a real hospital environment.

Future Work

While the current prototype achieves reliable room-level localization and telemetry streaming using cost-effective hardware, several advanced enhancements are planned for future iterations to scale the system for enterprise-grade hospital deployment:

1. Corner-Level Precision Indoor Tracking: Future developments will focus on moving beyond zone-level room recognition to sub-room spatial mapping. This will allow administrators to pinpoint the exact

location, shelf, or specific corner of a room where an asset is currently stationed.

2. Integration of Advanced Precision Hardware: To eliminate the need for manual room-switching cards and achieve automated continuous positioning, future versions will incorporate enterprise-grade hardware. This includes deploying Ultra-Wideband (UWB) real-time locating systems (RTLS) or dense Bluetooth Low Energy (BLE) beacon grids, enabling centimeter-level multi-dimensional tracking across complex hospital blueprints.

3. Machine Learning-Driven Predictive Maintenance: The telemetry pipeline will be expanded to incorporate machine learning models capable of predicting equipment failure and battery degradation trends based on historical core temperature and usage patterns.

4. Mobile Application Ecosystem: Developing dedicated native mobile applications for biomedical staff to receive instant push notifications and scan equipment directly from smartphones or handheld industrial scanners.

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