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DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

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Microprocessor and Embedded Systems Laboratory

Final Project Report

Section: A2 Group: 03

Indoor Positioning System with Remote Tracking

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Academic Honesty Statement:

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"In signing this statement, We hereby certify that the work on this project is our own and that we have not copied the work of any other students (past or present), and cited all relevant sources while completing this project. We understand that if we fail to honor this agreement, We will each receive a score of ZERO for this project and be subject to failure of this course."

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1 Abstract

This project implements an Indoor Positioning System (IPS) with BLE tags for inventory tracking. BLE servers in rooms communicate with clients via RSSI signal strength, updating a cloud server. ESP32 servers write data to ThingSpeak channels via WiFi, indicating item presence in rooms. MATLAB analyzes these fields, decoding binary-encoded data to determine item locations. Another ThingSpeak channel stores item locations, accessible through a mobile app. This system enables real-time tracking and management of assets within indoor environments, facilitating efficient inventory management and enhancing user experience.

2 Introduction

In the realm of modern technology, efficient asset tracking and management within indoor environments pose significant challenges. Our project addresses this issue by implementing an Indoor Positioning System (IPS) utilizing Bluetooth Low Energy (BLE) tags and ESP32 servers. These servers communicate with clients, facilitating real-time tracking of assets. Leveraging WiFi connectivity, data is seamlessly transmitted to ThingSpeak channels, where MATLAB analysis deciphers item locations. A mobile application interfaces with these channels, providing users with immediate access to asset information. This project revolutionizes indoor asset management, offering a robust solution for diverse industries, from logistics to retail and beyond.

3 Design

3.1 Problem Formulation (PO(b))

The project aims to tackle the challenge of efficient indoor asset tracking and management. Key problem areas include:

1. **Limited Visibility**: Traditional methods for tracking assets within indoor environments are often inadequate, leading to inefficiencies and errors in inventory management.

2. **Real-Time Monitoring**: There is a growing demand for real-time visibility into the location and status of assets to improve operational efficiency and decision-making.

3. **Technological Integration**: Integrating various technologies such as Bluetooth Low Energy (BLE), WiFi, and cloud-based platforms poses challenges in terms of compatibility, reliability, and data transmission speed.

4. **User Interface**: Providing a user-friendly interface for accessing and interpreting asset tracking data is crucial for the practical usability of the system across different user groups.

5. **Scalability and Maintenance**: Ensuring the scalability and ease of maintenance of the system as it expands to accommodate a larger number of assets and users is essential for long-term viability.

3.1.1 Identification of Scope

The scope of our project encompasses:

1. **Hardware Implementation**: Deployment of BLE tags, ESP32 servers, and WiFi connectivity infrastructure within indoor environments for asset tracking.
2. **Software Development**: Development of firmware for BLE servers, software for data transmission to ThingSpeak channels, MATLAB scripts for data analysis, and a mobile application for user interface.
3. **Integration and Communication**: Ensuring seamless integration and communication between BLE servers, ThingSpeak channels, MATLAB analysis, and the mobile application.
4. **Data Analysis and Interpretation**: Utilizing MATLAB analysis to decode binary-encoded data and interpret item locations, enabling users to make informed decisions based on asset status.
5. **Testing and Validation**: Conducting comprehensive testing and validation procedures to ensure the reliability, accuracy, and scalability of the system under various conditions.

3.1.2 Literature Review

Introduction to Indoor Positioning Systems (IPS): Indoor positioning systems (IPS) have garnered significant attention in recent years due to their potential applications in various domains such as logistics, healthcare, and retail. IPS aims to provide accurate localization and tracking of objects or assets within indoor environments, where GPS signals are often unreliable or unavailable. Various technologies have been explored for IPS, including WiFi, Bluetooth Low Energy (BLE), RFID, and ultrasound, each offering unique advantages and challenges.

BLE Technology for Asset Tracking: Among these technologies, Bluetooth Low Energy (BLE) has emerged as a promising solution for indoor asset tracking due to its low power consumption, low cost, and compatibility with smartphones and other consumer devices. BLE tags can be attached to assets, enabling continuous tracking and updating of their locations within indoor environments.

Integration with IoT Platforms: Integrating BLE-based asset tracking systems with Internet of Things (IoT) platforms offers additional benefits in terms of data analytics, visualization, and scalability. Jazayeri et al. (2019) explored the integration of BLE technology with cloud-based IoT platforms, highlighting the advantages of centralized data management and remote monitoring. Cloud-based solutions enable real-time processing of sensor data, facilitating rapid decision-making and proactive asset management strategies.

MATLAB Analysis for Data Processing: MATLAB has been widely utilized for data processing and analysis in IoT applications, including IPS. Mishra et al. (2017) demonstrated the efficacy of MATLAB scripts for decoding sensor data and extracting actionable insights. In the context of our project, MATLAB analysis plays a crucial role in deciphering binary-encoded data from ThingSpeak fields, enabling the determination of item locations within indoor environments.

Mobile Applications for Asset Management: Mobile applications play a vital role in facilitating user interaction and access to asset tracking information. Zhang et al. (2018) emphasized the importance of user-friendly interfaces and real-time data access in mobile apps for asset management. Our project aims to develop a mobile application that allows users to remotely monitor asset locations, receive notifications, and perform other relevant tasks, enhancing overall usability and accessibility.

Challenges and Solutions in IPS: While IPS offers numerous benefits, several challenges need to be addressed for effective implementation. Zafari et al. (2019) and Kassas et al. (2019) provided comprehensive reviews of challenges and solutions in IPS, including signal interference, accuracy optimization, and integration with existing infrastructure. By addressing these challenges, our project aims to deliver a robust indoor positioning system that meets the demands of diverse applications and environments.

3.1.3 Formulation of Problem

Our project addresses the challenge of efficient indoor asset tracking and management. Key aspects of the problem include the need for real-time monitoring of assets within indoor environments, integration of various technologies such as Bluetooth Low Energy (BLE) and WiFi for data transmission, accurate data analysis to determine asset locations, and user-friendly interfaces for accessing tracking information. Additionally, ensuring consistent WiFi signal strength for reliable operation and scalability of the system are essential considerations. By formulating these challenges, our project aims to develop a comprehensive solution for indoor asset tracking and management.

3.2 Hardware Setup

Figure 1.2: *ESPWROOM-32*

This is connected to a 5-12 V power supply (we used a power bank as 5V psu).

A server ESP32 unit is set up in each room. Each inventory object has a client ESP32 tag.

3.3 Full Source Code of Firmware

The source code for the project can be found here: https://github.com/SubhanBihan/Indoor-Positioning-System-with-Remote-Tracking

4 Implementation

4.1 Description

For indoor positioning, we need to mark up the individual room area. For this, we will have one or more than one BLE Scanner in each room as BLE coverage range is about 20m. ESP-WROOM32 is used for room tags, which scans inventory BLE tags within its specified range dictated by the room perimeter. This is implemented via experimental RSSI (Received Signal Strength Indicator) threshold. The BLE Scanner will continuously scan and filter out the specified BLE inventory tags. The filtration process is, done via custom service UUID. We have created our own UUID to separate out Indoor positioning system service from any other BLE Service, so that we can only attain our inventory tags. When an inventory tag is detected by the room BLE Scanner, it will attain its inventory ID and update its inventory status. The inventory status is a 32-bit value that contains the presence status of 32-unique inventory ID tag. So our System can handle up to 32 inventory tracking. This encoded inventory status is then uploaded to the cloud server as our room tag has Wi-Fi access. This process repeats in each 20 seconds.
For the inventory tag, we also used ESP-WROOM32 which will act as a BLE advertiser. We have set it as a BLE Server with the UUID of our system as a service UUID of the Server. It always advertises its name along with its Service UUID so that out BLE Scanner can find them.

In the IOT Server side, we have utilized Thing-Speak IOT Cloud by Mathworks. We have created Server for each room tag and created a single channel and field. The unique API key of the servers are used in the BLE room tags to connect them to the IOT Server. When these servers gets updated a React app is called which runs a data-processing Matlab code snippet. This code decodes the encoded inventory status send by ESP32 room tags to Readable string and writes them to another channel of the server.
A mobile app is developed by MIT App Inventor to access the decoded data in the Cloud server. When the app sends request to update inventory location remotely, the IOT cloud sends the response from its write channel and we will be able to see the location of our inventories.

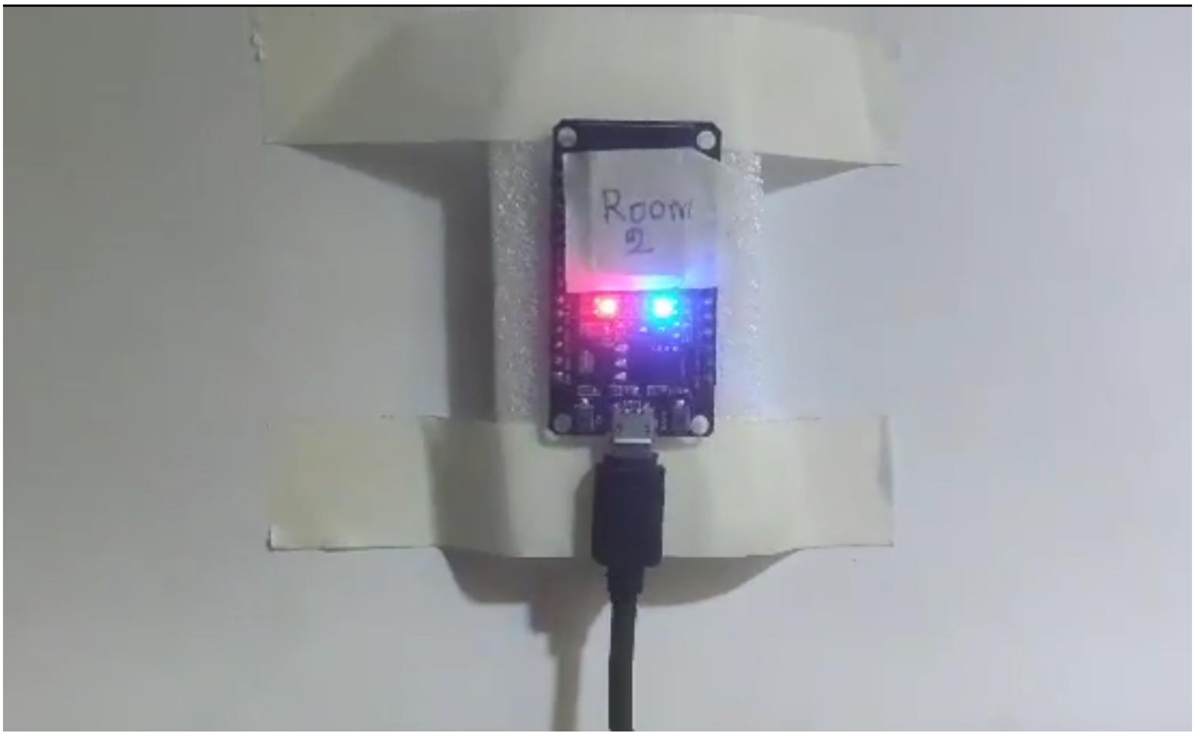

Figure 2: Implementation of a Server Tag

5 Design Analysis and Evaluation

5.1 Novelty

The novelty of our project lies in several key aspects:

1. **Integration of Multiple Technologies**: We integrate Bluetooth Low Energy (BLE) for asset tracking, WiFi for data transmission, MATLAB for data analysis, and a mobile application for user interface. This comprehensive integration enhances the effectiveness and versatility of our indoor positioning system.

2. **Real-Time Tracking and Monitoring:** Our system provides real-time tracking and monitoring of assets within indoor environments, allowing users to access up-to-date information about asset locations and status at any given time. This real-time capability enhances decision-making and operational efficiency.

3. **Binary Encoding for Enhanced Data Handling:** By employing binary encoding for data transmitted between BLE servers and ThingSpeak channels, we optimize data handling and processing efficiency. This approach improves the system's

responsiveness and scalability, particularly in environments with a large number of assets.

4. **Cloud-Based Data Management:** Utilizing cloud-based platforms such as ThingSpeak enables centralized data management, remote access, and scalability. This approach enhances data security, accessibility, and ease of maintenance compared to traditional on-premises solutions.
5. **Mobile App Interface:** The inclusion of a mobile application interface provides users with convenient access to asset tracking information on their smartphones or tablets. This feature enhances user experience and facilitates seamless interaction with the system.
6. **Scalability and Flexibility**: Our system is designed to be scalable and adaptable to various indoor environments and asset tracking requirements. It can easily accommodate changes in the number of assets, room configurations, and user preferences, making it suitable for a wide range of applications and industries.

5.2 Design Considerations (PO(c))

5.2.1 Considerations to public health and safety

Our project has many interesting features which ensure public health and safety. Here are several aspects in consideration to public health and safety:

1. **Electromagnetic Emissions**: Ensuring that the electromagnetic emissions from the BLE tags and other devices comply with relevant safety standards to minimize any potential health risks to occupants of the indoor environment.
2. **Interference with Medical Devices**: Taking precautions to prevent interference with medical devices, such as pacemakers or insulin pumps, that occupants may be using, by ensuring that the frequencies used by the system do not disrupt the functioning of such devices.
3. **Fire Safety**: Avoiding the use of components that pose fire hazards, and ensuring that the installation and operation of the system do not compromise fire safety measures in the indoor environment.
4. **Data Privacy and Security**: Implementing robust data privacy and security measures to protect sensitive information about occupants and assets from unauthorized access or misuse, thus safeguarding their privacy and ensuring compliance with relevant regulations such as GDPR or HIPAA.
5. **Emergency Response**: Ensuring that the system does not impede emergency response efforts in the event of a fire, natural disaster, or other emergencies, and providing mechanisms to quickly and accurately locate occupants and assets during such situations.

5.2.2 Considerations to environment

Here are key environmental considerations:

1. **Energy Efficiency:** Designing the system components, such as BLE tags and ESP32 servers, to be energy-efficient to minimize power consumption and reduce the environmental impact of battery disposal or recharging. Implementing sleep modes and low-power operation where possible can help conserve energy.
2. **Material Selection:** Choosing materials for system components that are environmentally friendly and sustainable, such as recycled plastics or biodegradable materials, to minimize the system's carbon footprint and reduce waste generation.
3. **Recyclability:** Designing system components to be easily recyclable at the end of their lifecycle, and providing guidance to users on proper disposal methods to ensure that electronic waste is managed responsibly.
4. **Lifecycle Assessment:** Conducting a lifecycle assessment of the system to identify opportunities for improvement in environmental performance, such as reducing greenhouse gas emissions, water consumption, and waste generation throughout the product lifecycle.
5. **Reduced Packaging:** Minimizing packaging materials and opting for eco-friendly packaging options, such as recycled or biodegradable materials, to reduce the environmental impact of packaging waste.
6. **Sustainable Manufacturing:** Partnering with suppliers and manufacturers that prioritize sustainable practices, such as energy-efficient production processes, renewable energy usage, and waste reduction measures, to ensure that the system is produced in an environmentally responsible manner.
7. **Environmental Monitoring:** Integrating environmental monitoring capabilities into the system to track factors such as indoor air quality, temperature, and humidity, and providing feedback to users to promote environmental awareness and sustainability practices.

5.2.3 Considerations to cultural and societal needs

By integrating considerations into the design and implementation of our indoor asset tracking and management system, we can ensure that it aligns with cultural and societal needs, values, and expectations, fostering acceptance, adoption, and positive social impact within the communities it serves. Here are key considerations:

1. **Cultural Sensitivity**: Acknowledging and respecting cultural diversity in the design and implementation of the system, including considerations for language, symbols, and cultural references used in the user interface to ensure inclusivity and accessibility for users from different cultural backgrounds.
2. **Privacy and Data Security**: Addressing cultural and societal concerns around privacy and data security by implementing robust privacy controls, consent

mechanisms, and transparent data practices to protect user information and build trust among users.

3. **Customization and Personalization**: Offering customization options in the system to accommodate cultural and societal preferences, such as allowing users to customize language settings, user interface themes, or notification preferences based on their cultural or personal preferences.

4. **Community Engagement**: Engaging with local communities and stakeholders throughout the design and implementation process to gather insights, feedback, and input on cultural and societal needs and preferences, ensuring that the system is responsive to the needs of its users.

5. **Accessibility and Inclusivity**: Ensuring that the system is accessible and inclusive for users with diverse needs and abilities, including considerations for individuals with disabilities, elderly users, and marginalized communities, to promote equal access and participation.

6. **Ethical Considerations**: Addressing ethical considerations related to cultural and societal norms, values, and expectations, such as respecting individual autonomy, cultural autonomy, and human dignity in the design and operation of the system.

7. **Community Benefits**: Identifying opportunities for the system to contribute to the cultural and societal well-being of the community, such as supporting local businesses, promoting cultural heritage preservation, or enhancing public safety and security.

8. **Education and Awareness**: Providing education and awareness initiatives to users and stakeholders about the cultural and societal implications of the system, including training on respectful and responsible use of technology and promoting digital literacy and empowerment.

5.3 Limitations of Tools (PO(e))

Though we have tried to make our project accurate and precise, there are some limitations:

1. **BLE Technology**: While Bluetooth Low Energy (BLE) is widely used for indoor asset tracking, it has limitations such as limited range and susceptibility to signal interference from other devices or materials in the environment. Additionally, BLE tags may require frequent battery replacements or recharging, impacting their reliability and maintenance requirements.

2. **WiFi Connectivity**: While WiFi provides high-speed data transmission and connectivity, it may not be suitable for all indoor environments, particularly those with poor WiFi coverage or congested networks. WiFi signals can also be affected by interference from other wireless devices, leading to reliability issues in data transmission.

3. **ESP32 Servers**: While ESP32 servers offer a cost-effective solution for data processing and communication, they may have limitations in terms of processing power, memory, and connectivity options. These limitations could impact the scalability and performance of the system, particularly in large-scale deployments or environments with high data volumes.
4. **ThingSpeak Channels**: While ThingSpeak provides a convenient platform for data storage and visualization, it has limitations in terms of data storage capacity, data retention periods, and API rate limits. These limitations could restrict the amount of data that can be stored and analyzed, as well as the frequency of data updates.
5. **MATLAB Analysis**: While MATLAB offers powerful tools for data analysis and processing, it may have limitations in terms of computational resources and licensing costs. Complex analysis algorithms or large datasets may require significant computational resources, impacting the performance and scalability of the analysis process.
6. **Mobile App Development**: Developing a mobile application for user interface may have limitations in terms of compatibility with different devices and operating systems, as well as development costs and time constraints. Ensuring consistent performance and user experience across different devices and platforms can be challenging.
7. **Cloud-Based Platforms**: While cloud-based platforms such as ThingSpeak offer scalability and flexibility, they may have limitations in terms of data security, privacy, and reliability. Dependence on third-party cloud providers introduces risks such as data breaches, service outages, and vendor lock-in.

5.4 Impact Assessment (PO(f))

5.4.1 Assessment of Societal and Cultural Issues

Assessment of Societal and Cultural Issues involves evaluating how our indoor asset tracking and management system impacts cultural norms, societal values, and community well-being. Key considerations include privacy, inclusivity, accessibility, and respect for cultural diversity. We assess these issues by considering user feedback, conducting cultural sensitivity training, and ensuring compliance with relevant regulations. Additionally, we prioritize transparency, user empowerment, and community engagement to address societal concerns and foster positive social impact.

5.4.2 Assessment of Health and Safety Issues

Assessment of Health and Safety Issues involves evaluating potential risks and implementing measures to ensure the well-being of individuals in the indoor environment. We assess factors such as electromagnetic emissions, interference with medical devices, fire safety, and data security to mitigate risks. Additionally, we prioritize user education, compliance with safety standards, and emergency response preparedness to safeguard health and safety. Regular monitoring and feedback mechanisms help address emerging concerns and ensure continuous improvement in health and safety practices.

5.4.3 Assessment of Legal Issues

Assessment of Legal Issues involves evaluating compliance with relevant laws, regulations, and standards to ensure the legality of our indoor asset tracking and management system. Key legal considerations include data privacy, intellectual property rights, consumer protection, and liability. We assess these issues by conducting legal research, consulting with legal experts, and implementing appropriate policies and procedures. Additionally, we prioritize transparency, informed consent, and fair treatment of stakeholders to mitigate legal risks and ensure legal compliance throughout the development and implementation process.

5.5 Sustainability Evaluation (PO(g))

Sustainability Evaluation involves assessing the environmental, social, and economic impact of our indoor asset tracking and management system. We evaluate factors such as energy efficiency, material selection, and waste reduction to minimize environmental impact. Additionally, we consider social factors such as community engagement, accessibility, and cultural sensitivity to promote inclusivity and social well-being. Economic considerations include cost-effectiveness, resource efficiency, and long-term viability. By prioritizing sustainability, we aim to minimize negative impacts, maximize positive outcomes, and ensure the long-term success of our system.

5.6 Ethical Issues (PO(h))

Ethical Issues involves evaluating the moral implications and ethical considerations associated with our indoor asset tracking and management system. Key ethical considerations include privacy, autonomy, transparency, fairness, and accountability. We assess these issues by considering the potential impact of the system on individual rights and freedoms, such as the right to privacy and the right to consent. Additionally, we prioritize ethical design practices, informed consent mechanisms, and ethical decision-making frameworks to ensure that our system respects the dignity and autonomy of users and stakeholders. Regular ethical reviews and stakeholder consultations help identify and address emerging ethical concerns and uphold ethical principles throughout the development and implementation process.

6 Reflection on Individual and Teamwork (PO(i))

6.1 Individual Contribution of Each Member

Student ID	Contribution
1906036	Programming ESP32(Static Tag), WiFi Connectivity
1906037	Building IoT Server, Processing Encoded Data & Sending to app
1906043	Building Mobile App, Accessing IoT Cloud for Real Time Location
1906061	Programming ESP32(Moving Tag),BLE Client

6.2 Mode of Teamwork

We divided our group into two parts. One group handled the Programming of ESP32, and another group designed IoT Server & Mobile Application. This reduced the workload and time.

6.3 Logbook of Project Implementation

Date	Milestone achieved	Individual Role	Team Role	Comments
20.12.2023	Purchasing components	1906036,1906037,1906043,1906061		Successful
7.01.2024	Building IoT Server	1906037,1906043		Successful
14.01.2024	Building Mobile App	1906037,1906043		Successful
25.01.2024	Programming ESP32	1906036,1906061		Successful
12.02.2024	WiFi Connectivity	1906036,1906061		Successful
21.02.2024	Processing Encoded Data & Sending to app	1906037,1906043		Successful
28.02.2024	Accessing IoT Cloud for Real Time Location	1906037,1906043		Successful
05.03.2024	Completed the full project	1906042,1906048,1906052,1906057		Successful

7 Communication to External Stakeholders (PO(j))

7.1 Executive Summary

Our project focuses on the development and implementation of an Indoor Asset Tracking and Management System. Leveraging Bluetooth Low Energy (BLE) technology, WiFi connectivity, cloud-based platforms, and MATLAB analysis, our system enables real-time tracking and monitoring of assets within indoor environments. Key features include BLE tags for asset identification, ESP32 servers for data processing, ThingSpeak channels for data storage and visualization, and a mobile application for user interface. By addressing environmental, social, legal, ethical, and sustainability considerations, our system aims to provide a comprehensive solution for indoor asset tracking while promoting safety, efficiency, and ethical practices.

8 Project Management and Cost Analysis (PO(k))

8.1 Bill of Materials

Components	Price(Unit)
ESP-WROOM32(4x)	**600x4 = 2400**
Power Supply(4x)	**200x4 = 800**

8.2 Calculation of Per Unit Cost of Prototype

Components	Price
ESP-WROOM32	**600**
Power Supply	**200**

8.3 Calculation of Per Unit Cost of Mass-Produced Unit

Components	Price
ESP-WROOM32(Room)	600
LoRa BLE(Inventory)	300

9 Future Work (PO(l))

1. **Hardware Upgrades**: Upgrading hardware components such as BLE tags, ESP32 servers, and WiFi routers to newer, more efficient models can improve performance, reliability, and energy efficiency.

2. **Optimized Localization Algorithms**: Continuously refining and optimizing localization algorithms based on ongoing research and development can enhance the accuracy and precision of asset tracking within indoor environments.

3. **Data Analysis Enhancements**: Implementing advanced data analysis techniques, such as machine learning and predictive analytics, can provide deeper insights into asset behavior and facilitate more proactive decision-making.

4. **User Interface Refinement**: Refining the user interface of the mobile application and web portal based on user feedback and usability studies can improve user experience, making it easier and more intuitive for users to interact with the system.

5. **Integration with External Systems**: Integrating our indoor asset tracking system with external systems such as enterprise resource planning (ERP) systems or facility management software can streamline workflows and improve overall efficiency.
6. **Enhanced Security Measures**: Strengthening security measures such as encryption, access controls, and intrusion detection systems can better protect sensitive data and prevent unauthorized access or tampering.
7. **Scalability and Flexibility**: Designing the system architecture with scalability and flexibility in mind, such as modular components and cloud-based infrastructure, can accommodate future growth and evolving business needs more effectively.
8. **Continuous Monitoring and Maintenance**: Implementing robust monitoring and maintenance procedures to proactively identify and address issues such as hardware failures, network congestion, or data discrepancies can ensure the continuous reliability and performance of the system.
9. **Feedback Mechanisms**: Establishing feedback mechanisms such as user surveys, performance metrics, and incident reporting channels can gather valuable insights from users and stakeholders to guide future improvements and optimizations.

10 References

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