Smart Warehouse Inventory Tracker

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***Abstract*—This paper presents the Smart Tracker project, focusing on developing a comprehensive Smart Warehouse Inventory Tracker for indoor environments. The system aims to provide precise location information, allowing the real-time tracking of assets in warehouses using Bluetooth Low Energy (BLE) and microcontroller units (MCUs) such as M5StickC Plus and Raspberry Pi.**

***Index Terms*—Bluetooth Low Energy (BLE), Internet of Things (IoT), Location Tracking, Vertical Positioning**

I. Introduction

In the ever evolving landscape of logistics, the precise tracking of warehouse assets not only affords convenience, but is also strategically essential in the efficient warehouse operation. While various technologies like Ultra-Wideband (UWB), RFID, and Wi-Fi have made advancements in indoor positioning, accurately tracking an object's vertical location in indoor environments remains a challenge.

In this context, the paper presents the Smart Warehouse Inventory Tracker project, which aims to provide precise location information of assets within indoor environments in real time. The project employs Bluetooth Low Energy (BLE) and microcontroller units (MCUs) like M5StickC Plus and Raspberry Pi to ensure accurate three-dimensional tracking of assets [1].

At the core of this system, BLE serves as the communication backbone by fostering connectivity between sensor nodes and asset nodes, while MCUs serve as the brains of the operation by processing data, executing algorithms, and facilitating real-time communication [2]. By employing a trilateration algorithm and strategically placing BLE-enabled nodes in the indoor space, the Smart Warehouse Inventory Tracker aims to overcome the challenges associated with vertical tracking.

This paper outlines the system's objectives, addressing the limitations in current indoor tracking systems and presenting a solution that aims to enhance accuracy and efficiency in warehouse asset tracking.

II. Problem Statement

The Smart Warehouse Inventory Tracker project aims to improve the efficacy of location tracking of an object in complex multipath environments, such as an indoor building. As of now, there are multiple approaches towards indoor positioning such as Ultra-Wide-Band positioning, RFID positioning, WIFI positioning, and Bluetooth Beacons. However, current implementations of indoor tracking all have one similar limitation - the locational accuracy of an object/person in a vertical position. Vertical positioning has been utilised in our day-to-day lives, from navigation within shopping malls to using vertical location positions in fire and rescue emergency responses (firefighting). This project focuses on tracking the location of an object vertically, laterally, and longitudinal, within an indoor environment.

III. Objectives

The primary objectives of the Smart Tracker project include:

- Establishing a network of BLE-enabled nodes for comprehensive coverage of the indoor area.
  - Vertical Location Tracking: The prevailing generation of IoT sensors grapples with challenges in effectively and accurately tracking objects vertically within an indoor environment. This limitation poses a substantial impediment to achieving precise and reliable tracking outcomes which this project is looking to solve.
- Developing algorithms for locating the position of assets based on signals received from these nodes.
  - Trilateration Algorithm: Utilizing signals from multiple strategically positioned BLE nodes, our algorithm accurately calculates asset positions by determining the intersection point of circles/spheres based on known distances between the asset and each node.

- Implementing real-time data processing mechanisms to accurately update asset positions.
- Evaluating the system's performance in terms of accuracy, reliability, and scalability.
  - Enhanced Accuracy: The proposed solution focuses on the reliability and accuracy of location tracking within an indoor environment. An object/item will be attached to a sensor node, and by utilising BLE beacons/nodes placed in the corners of the room, the sensor node on the item will be able to calculate its position using trilateration.

IV. Literature Review

The study examines the utilisation of Ultra-Wideband (UWB) and barometers for indoor positioning. UWB technology, transmitting high-bandwidth pulses in short cycles, is explored for indoor navigation but faces challenges such as real-time calculation dependence on factors like Time-of-arrival (TOA) and environmental issues like Non-Line-of-sight (NLOS). Barometers, while affected by environmental factors like temperature, are combined with UWB to enhance vertical position accuracy. Despite potential inaccuracies, combining barometers with UWB improves vertical positioning, as observed in Li et al.'s study and similar findings from others integrating barometers with technologies like Wi-Fi and iBeacons [3][4][5][6][7][8].

RFID-based tool-tracking systems for construction sites can also be considered. RFID technology offers real-time tracking, but metal interference is a concern. Integration with sensor networks improves accuracy, yet deploying multiple IoT protocols may be complex. RFID tagging and mobile scanners enable data management, but economic and range limitations persist. Comparative analysis of tracking algorithms provides insights, but dynamic construction environments pose challenges. Despite RFID's promise, overcoming metal interference and deployment complexities is crucial. Further research is needed to optimize scalability, standardization, and data management in construction environments [9].

Yoo et al. (2018) studied real-time location systems (RTLS) in hospitals to improve productivity, using WiFi for general tracking and BLE beacons for precise areas. Their system integrates with the hospital's information system, enabling users to monitor asset location and battery status. Clear asset selection streamlines inventory, but technical challenges include occasional inaccuracies due to radio wave disruptions. Battery reliance poses issues with draining and replacement, while larger tags sacrifice adhesive power. These insights provide valuable guidance for implementing similar systems in warehouses, considering trade-offs between accuracy, energy, and tag size [10].

Nissen et al. apply Q-learning for cost minimization. Meller et al. use Linear Quantile Regression and Tree-Based Models considering factors like traffic and climate for better predictions. Haijema explores optimizing ordering and disposal policies based on stock age and demands and enforcing FIFO rules. Agrawal and Srikant utilize the Apriori Algorithm to predict item associations, enhancing inventory management efficiency. These methods prioritize products based on demand, crucial for sustaining perishable goods in inventory management [11].

Lee et al. (2019) explore a Bluetooth-based indoor positioning system for warehouse asset tracking, emphasizing BLE technology and introducing a Kalman-LULU filter for enhanced accuracy. Their system, employing beacons and Raspberry Pi, leverages RSSI for distance estimation. The study investigates metal attenuation effects and unexpected interference from nearby beacons. While effective, Lee et al.'s system lacks focus on vertical tracking and workshop tools. In contrast, the Smart Tracker project addresses these limitations, employing node augmentation for accuracy and scalability in 3D spaces. Tailored for workshop scenarios, it aims to provide a more holistic solution for indoor asset tracking [12].

A. Summary

The Smart Warehouse Inventory Tracker project addresses limitations in vertical tracking within 3D indoor spaces. Augmenting the sensor network enhances accuracy, focusing on asset precision. Literature supports BLE/WiFi integration for real-time asset tracking, despite challenges like battery life and metal interference. UWB offers the potential for precise indoor positioning, though challenges in environmental factors persist. The trilateration algorithm utilising RSSI and Kalman Filter, aligns with project objectives. RFID, while effective, faces challenges like metal interference in construction sites. Overall, the project opts for BLE due to its simplicity and cost-effectiveness despite its challenges and the usage of the trilateration for its relevance to the project.

V. Design

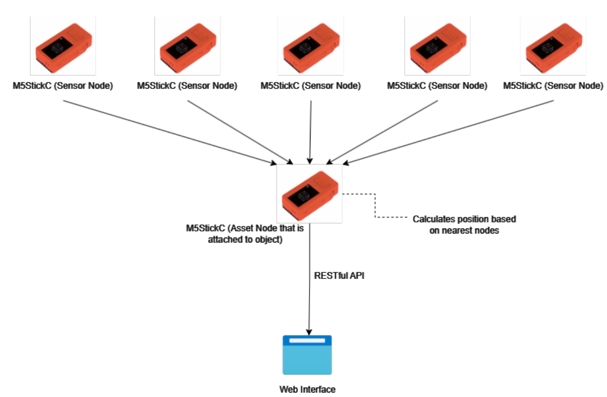

Fig. 1. Smart Warehouse Inventory Traacker System Architecture

The system architecture, as depicted in Figure 1, illustrates the general layout of the proposed solution. Each Sensor Node will be placed in each corner of a room. An additional Sensor Node will be placed at the rooms tallest point. An object that is attached to an Asset Node will calculate its relative position based on trilateration. After its position has been determined, the Asset Node will send its locational data to an interface.

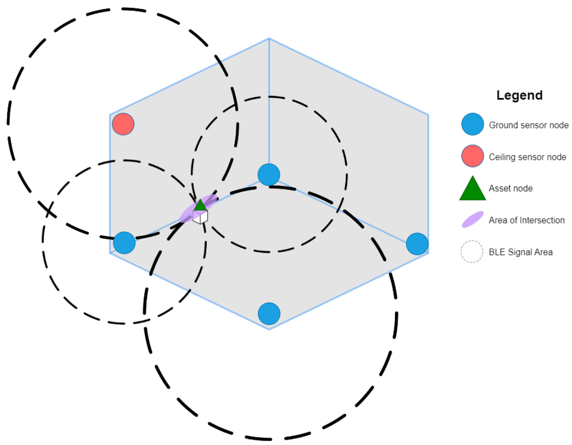

Fig. 2. Indoor Asset Tracking Layout

Each Asset Node will send its locational data to the interface. This interface, as visualised in Figure 2, is designed to display the positions of all Asset Nodes in the rooms vicinity.

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