

DESIGN AND IMPLEMENTATION OF AN INVENTORY MANAGEMENT WITH RF-BASED ASSET TRACKING SYSTEM IN ACADEMIC SETTING

Josh Marc R. Ricalde, Ruben Christopher L. Macabata and Mariciel M. Teogangco

College of Engineering, University of Perpetual Help System Dalta, Molino Campus, Philippines

Abstract

This study endeavors to design and implement an innovative asset detection device and inventory system utilizing Radio Frequency (RF) technology to bolster asset monitoring and inventory management in school laboratories. The primary objectives are twofold: developing an RF tracker device capable of detecting passive RF tags within a designated area and creating an asset inventory system software tailored for the Electronics Laboratory at the university. The study's first phase focuses on the design and fabrication of the RF tracker device engineered to detect passive RF tags within a 6.5x6.5-meter space. Through meticulous design considerations, the device aims to provide precise asset-tracking capabilities within the laboratory environment. The second phase involves the development of asset inventory system software customized to meet the specific needs of the University's Electronics Laboratory. This software will facilitate efficient asset management by accurately capturing and storing each asset's X and Y coordinates within the room. Evaluation metrics encompass the accuracy of asset localization, the efficiency of inventory management processes, and the system's overall operational efficiency and user-friendliness. The recorded results show that the scanned positions of assets closely match their real positions, with only minor deviations observed. ANOVA analysis confirms that there is no significant difference between real and scanned coordinates, validating the accuracy of the RF-based asset tracker. Efficiency comparison highlights that the designed tracker drastically reduces borrowing and returning time compared to the traditional manual method. Overall, the tracker improves asset management by ensuring precise location tracking and significantly enhancing operational efficiency.

Keywords:

Radio Frequency, long-range RF, Asset Tracker, Asset Monitoring, RFID, Raspberry Pi 3, Arduino Uno

1. INTRODUCTION

The university's Electronics Laboratory serves as crucial training grounds for future ECE. These labs house specialized equipment essential for hands-on learning and research activities. However, ensuring these valuable assets' efficient utilization, security, and real-time location can be a significant challenge. Traditional asset tracking methods, often relying on manual inventory control, are prone to human error, time-consuming, and cannot provide real-time data. To tackle these challenges and enhance asset accountability, this research proposes implementing an RF-based asset tracking system for laboratory assets and equipment in the University by creating a comprehensive RF system. The university's Electronics Laboratory can efficiently track and manage the movement and usage of assets, enabling real-time detection of who has borrowed or accessed specific objects.

Asset tracking using RF for equipment in the Electronics Communication Laboratory is rooted in the growing need for efficient and effective asset management in academic institutions [1]. The study aims to explore the implementation of RF

technology to address the challenges of traditional asset-tracking methods and capitalize on the benefits of real-time data collection, simultaneous tracking, and increased security [2]. Prior studies have demonstrated the feasibility and effectiveness of RF asset tracking systems in various applications, including research labs, where RF has been used to track scientific instruments, digital measuring equipment, and other lab equipment, leading to improved auditing, inventorying, and equipment movement tracking [3]. Additionally, RF technology has been widely used in various industries for asset tracking, personnel tracking, ID badging, supply chain logistics, and restricted areas access control [4].

Effective asset management is essential in educational institutions, particularly in university laboratories where a large number of electronic instruments, tools, and equipment are frequently shared among students, faculty members, and laboratory staff. Conventional asset inventory practices generally rely on manual identification, recording, borrowing, and returning procedures, which can be time-consuming and may result in inaccurate records, misplaced equipment, and difficulties in determining the real-time location of assets. Radio Frequency Identification (RFID) and Radio Frequency (RF) technologies provide opportunities to automate these processes by enabling contactless identification and tracking of tagged assets. However, laboratory environments require a practical tracking solution that can identify passive RF tags within a defined area while maintaining acceptable localization accuracy and operational simplicity. In this context, the integration of RF-based sensing with embedded platforms such as Raspberry Pi and Arduino can provide a cost-effective approach for developing an automated laboratory asset monitoring system. The proposed work therefore focuses on designing an RF tracker capable of detecting passive RF-tagged assets within a 6.5×6.5 m laboratory area and integrating it with inventory management software for recording and monitoring asset positions. The system is intended to reduce dependency on manual inventory procedures while improving asset visibility, accessibility, and borrowing and returning efficiency. The benefits of RF asset tracking include real-time data collection, accurate data inventory, simplified monitoring and storage processes, reduced human involvement, deterrence of asset loss, increased security, and centralized data history about items' location and use [5]. Therefore, the study is supported by the need for efficient asset management in academic institutions and the proven benefits of RF technology in various industry applications [6].

In educational institutions, proper management of school assets and other valuable objects is crucial for maintaining a safe and conducive learning environment. However, the lack of a robust and efficient asset-tracking system poses significant challenges in maintaining asset accountability and optimizing resource utilization. Manual asset tracking methods, such as paper-based records or spreadsheets, are labor-intensive and

prone to errors, making it difficult to promptly detect asset movement and usage. This limitation disrupts school operations and exposes institutions to potential security risks and financial losses due to asset mismanagement. Additionally, the absence of real-time visibility into asset availability and usage hampers the efficient management of resources, leading to administrative inefficiencies and increased operational costs. Without an automated asset tracking system, schools struggle to make data-driven decisions about asset allocation, resulting in sub-optimal resource utilization and potential duplication of assets.

The general objective of this study is to design and develop an asset detection device and inventory system to enhance asset monitoring and inventory management in school laboratories using RF technology. Specifically, the study aims to design an RF tracker device to detect passive RF tags within a 6.5x6.5m area, develop an asset inventory system software for the university's Electronics laboratory, and evaluate the system in terms of accuracy in locating each asset's coordinates inside the room, efficiency of inventory management, and accessibility and user-friendliness. This comprehensive approach aims to address the challenges of asset tracking and management in academic settings, ultimately improving the efficiency and security of laboratory operations.

The primary contribution of this research is the design and implementation of an RF-based asset detection and inventory management system specifically tailored for university electronics laboratories. The proposed system combines a fabricated RF tracker device with an inventory software platform to automatically detect passive RF-tagged assets and determine their approximate X and Y coordinates within the laboratory environment. A further contribution is the development of a practical laboratory-scale tracking framework using Raspberry Pi 3 and Arduino Uno, enabling integration between RF sensing, coordinate acquisition, and inventory records. The research also experimentally evaluates the localization accuracy by comparing scanned asset positions with their actual positions and applying ANOVA to determine whether statistically significant differences exist between the measurements. In addition, the study compares the borrowing and returning processes of the proposed system with the conventional manual approach to assess operational efficiency. The results demonstrate that the proposed approach can achieve close correspondence between actual and scanned asset positions while substantially reducing the time required for asset borrowing and returning. Thus, the research contributes a practical and automated solution for improving asset visibility, inventory accuracy, and operational efficiency in laboratory environments.

2. LITERATURE REVIEW AND IDENTIFIED LIMITATIONS

Previous research has demonstrated the growing importance of automated asset management, RFID, IoT, and real-time location technologies across healthcare, transportation, education, and supply-chain environments. Yoo et al. [1] investigated real-time location system-based asset tracking in healthcare and demonstrated the feasibility of automated asset localization; however, the study was primarily focused on healthcare environments and did not address the specific spatial and

operational constraints of educational laboratories. Krugler et al. [2] and Petchrompo and Parlikad [3] highlighted the importance of systematic asset management and decision-making for managing multiple assets, but their works mainly concentrated on conceptual, analytical, and large-scale asset-management perspectives rather than real-time laboratory-level tracking. Kleindorfer and Saad [4] emphasized the importance of managing operational disruptions and risks, while Stone [5] discussed the practical adoption of asset-tracking technologies in K–12 schools; nevertheless, these studies provide limited insight into precise indoor localization and coordinate-based identification of individual laboratory equipment. Koste and Malhotra [6] examined flexibility in operational systems, but the work was developed in the manufacturing context and does not directly address automated inventory tracking in academic laboratories. Tan and Sidhu [7] reviewed the integration of RFID and IoT in supply-chain management and identified the potential of connected identification and monitoring technologies, although their review primarily considered supply-chain applications rather than small indoor laboratory spaces. The RFID system implementation presented in [8] establishes the technical foundation for RFID-based identification, but it does not sufficiently address coordinate-level asset localization or comparative evaluation against manual laboratory inventory procedures. Similarly, the mobile-based laboratory inventory framework reported by De La Salle University [9] demonstrates the usefulness of computerized inventory management but does not provide an integrated RF-based physical localization mechanism. Deepika et al. [10] demonstrated the usefulness of IoT technologies for monitoring campus infrastructure, whereas Ingrid [11] described practical asset-tracking practices for educational institutions; however, these works provide limited experimental validation of position accuracy and do not establish a complete combination of RF detection, coordinate localization, and inventory management. Chandra et al. [12] further illustrates the application of intelligent IoT-based systems in monitoring and automation, but its focus on energy management rather than physical asset tracking limits its direct applicability to laboratory inventory management. From the reviewed literature, several gaps can therefore be identified: existing studies frequently address asset identification, inventory management, or real-time monitoring independently, while comparatively less attention has been given to integrating RF-based physical localization with laboratory inventory software. Many existing approaches are also designed for healthcare, transportation, manufacturing, supply-chain, or general campus applications and may not account for the confined spatial characteristics, equipment movement, and borrowing/returning procedures of university laboratories. Furthermore, limited studies quantitatively validate localization accuracy by comparing actual and detected X–Y coordinates and statistically examining their differences. The efficiency of automated RF tracking compared with conventional manual borrowing and returning procedures is also insufficiently investigated. These limitations motivate the present work, which develops an RF-based asset tracker for a defined 6.5×6.5 m laboratory area and integrates it with inventory software to provide coordinate-based asset monitoring, while experimentally evaluating localization accuracy, statistical significance, operational efficiency, and usability.

3. METHODOLOGY

The proposed methodology develops an integrated RF-based asset detection and inventory management system for monitoring laboratory equipment and determining its approximate location within a defined indoor environment. The overall methodology consists of five major stages: asset tagging, RF-based asset detection, coordinate estimation, inventory database development, and system evaluation. Initially, each laboratory asset is assigned a unique passive RF/RFID tag containing an identifiable tag ID. The tags are physically attached to the corresponding laboratory equipment so that each asset can be uniquely recognized during the scanning process. The proposed system is deployed in a 6.5 × 6.5 m Electronics Laboratory, and the laboratory area is represented using an X–Y coordinate system. The RF tracker is designed using an embedded controller-based architecture incorporating the required RF/RFID sensing components, with Arduino Uno and Raspberry Pi 3 used for sensing, processing, and communication functions. During scanning, the RF reader detects the passive tags present within the designated area and retrieves their unique identification information. The detected information is processed by the controller and associated with the corresponding asset record in the inventory database. Based on the tracker configuration and detected asset information, the system determines and records the corresponding X and Y positions of the assets. The inventory management software provides dedicated modules for room monitoring, asset registration, inventory management, settings, transaction history, and notification alerts. When an asset is borrowed or returned, the system updates its status and records the corresponding transaction, thereby reducing dependence on manual inventory documentation. The recorded real and scanned positions are subsequently compared to evaluate localization accuracy. Statistical validation is performed using single-factor ANOVA at a significance level of 0.05, while the operational performance is evaluated by comparing the time required for asset borrowing and returning using the proposed system against the conventional manual procedure. The methodology therefore provides an integrated framework in which RF-based identification, indoor asset localization, computerized inventory management, and performance evaluation are combined to improve the accuracy and efficiency of laboratory asset monitoring.

3.1 RESEARCH DESIGN AND LOCALE

Asset tracking systems utilizing Radio Frequency (RF) technology have gained significant importance due to their ability to automatically track assets, enhancing asset management efficiency. These systems rely on RF tags to send data to readers using magnetic fields. The researchers established an asset tracker and an asset monitoring system for the Radio Frequency technique study. The researchers used the twenty (20) selected assets inside the Electronics Laboratory of the University. For the RF scanner, researchers used a 4-meter long-range UHF scanner attached to two (2) servo motors for X-axis and Y-axis movement and installed in a pole at the center of a 6.5m x 6.4m laboratory.

The use of RF technology allows for real-time tracking of assets within buildings or institutions, overcoming the limitations of GPS systems. Researchers installed the system in the

Electronics Laboratory of the university since it had more than enough space to accommodate the researchers, had the ideal assets that researchers needed, and the location was convenient to the researchers.

3.2 SCHEMATIC DIAGRAM OF ASSET TRACKER SYSTEM

This diagram illustrates the schematic diagram of the asset tracker system, from the power supply to the Raspberry Pi 3 to run the system and lastly to the Arduino Nano that controls the Servo.

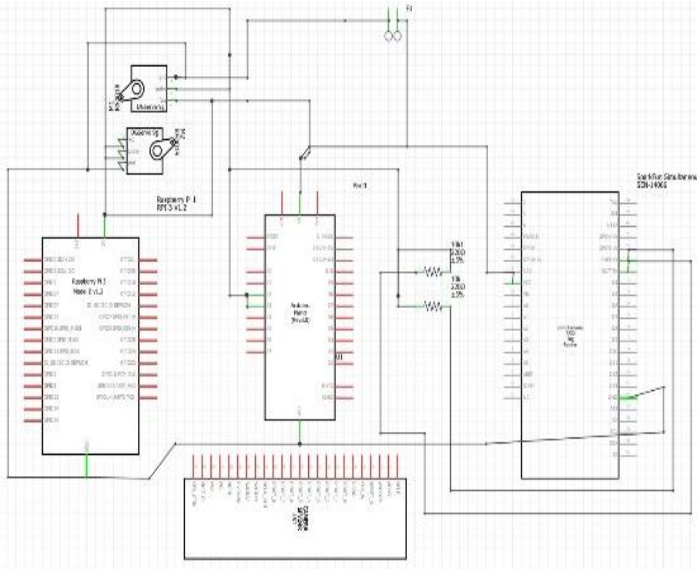


Fig.1. Schematic Diagram of Asset Tracker System

3.3 WIRING DIAGRAM OF ASSET TRACKER SYSTEM

This diagram illustrates the main components and their wiring connection of the asset tracker device.

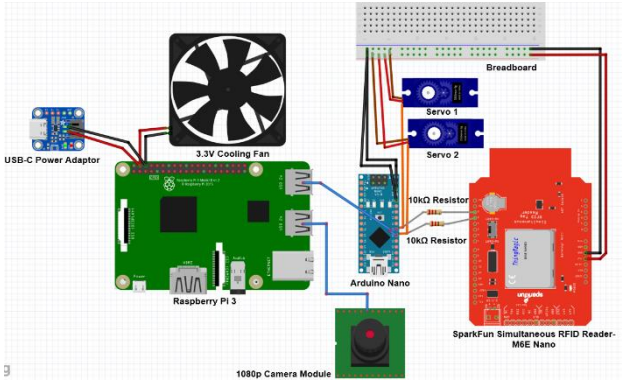


Fig.2. Wiring Diagram of Asset Tracker System

3.4 SOFTWARE DEVELOPMENT METHODS

The researchers employed a common software development style called Agile style for iterative development. Agile methodology is a flexible and iterative approach to software development that stresses collaboration, customer input, and quick delivery of functioning software [26].



Fig.3. Agile method concept

The software was created by considering the long-range RFID reader, Raspberry Pi, and a web application.

- **Client-Server Model:** The Raspberry Pi devices function as clients, reading RFID tags and transmitting data to a central server. The central server handles this data, updates the database, and serves the web application.
- **Local Network:** The Raspberry Pi devices and the central server are linked via a local network in the laboratory. Ensures fast, dependable communication and data transfer without requiring external internet connectivity.
- **Web Application:** The web application provides a user interface for laboratory staff to monitor, manage, and report on asset data. Web browsers on computers, tablets, and smartphones provide flexible access to the system.

The software used combination of several key programming languages to improve functionality and user experience. HTML is used to structure the front end of the web application, which provides an easy-to-use interface for monitoring and managing laboratory assets. JavaScript adds interactivity and dynamic content, allowing for updates to asset locations and statuses. On the server, PHP handles client requests, communicates with the MySQL database (which stores critical data such as laboratory assets, RFID tag information, user accounts, and system logs), and returns appropriate responses to the client. Furthermore, the Arduino IDE is used to write and upload code to Arduino microcontrollers, which control hardware components such as servo motors for automated tasks in the laboratory, streamlining operations and increasing efficiency.

3.5 DATA GATHERING METHODS

The researchers established an Asset Tracker using RF technology with an Asset Monitoring System. The testing period lasted five (5) trials, as the RF reader is a 4m long-range reader. Each asset that needs to be tracked is affixed with an RF tag, which contains a unique identifier and can store additional information about the asset. RF readers or scanners are strategically placed throughout the facility or environment where the assets are located. These readers emit radio frequency signals and capture the data transmitted by the RF tags when they come within range. As assets move within the range of the RF readers, the readers detect and capture the unique identifier from the RF tags. This data is then transmitted to a central database or software system for processing and further analysis. After the testing period, researchers used ANOVA- single factor to prove that the

asset monitored to a radio frequency asset tracking exhibited an accuracy in determining the location of the asset. The development of this study took conceptual literature and similar works into consideration. The researchers analyzed the earlier models' design, build, and functions and added modifications to improve the present RF asset tracker. The study considered the knowledge of current technology that can be adjusted to create a design for RF asset tracker. The researcher looked for familiar studies, both foreign and local, that correlate with the findings.

4. RESULTS AND DISCUSSION

The proposed RF-based asset tracker was experimentally evaluated in a university Electronics Laboratory to determine its ability to identify and localize tagged laboratory assets and to improve inventory management efficiency. The experimental environment consisted of a 6.5 m × 6.5 m laboratory area, within which passive RF/Rfid tags were attached to the selected laboratory assets. A total of 20 assets were considered for the localization experiment. Each asset was assigned a known physical position represented by its X and Y coordinates. The RF tracker was positioned and configured to scan the designated laboratory area, while the embedded control system was used to acquire the detected tag information and transmit the corresponding position data to the inventory management software. The experimental parameters included a laboratory area of 42.25 m², 20 tagged assets, two-dimensional X–Y coordinate localization, real-position measurements as the reference values, and scanned-position measurements obtained from the proposed tracker. The system software further included room monitoring, asset inventory, settings, history, and notification functions, as illustrated in Fig.4–Fig.7. For each asset, the actual position was recorded before scanning, after which the same asset was detected using the RF tracker and its corresponding scanned coordinates were recorded. The collected observations were subsequently analyzed using descriptive statistics and one-way ANOVA (single factor) at a significance level of $\alpha = 0.05$ to determine whether the difference between the real and scanned positions was statistically significant. In addition, the time required to borrow and return assets using the conventional manual procedure was compared with the proposed tracker-based procedure.



Fig.4. Room Monitoring



Fig.5. Settings

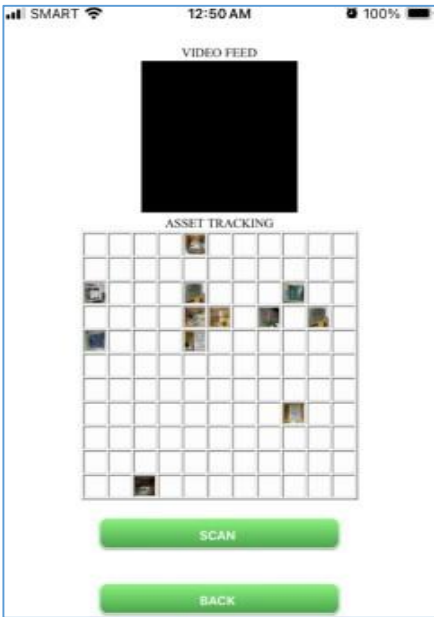


Fig.6. Information associated with laboratory assets

The Fig.4 presents the room-monitoring interface of the proposed system, which provides a visual representation of assets within the laboratory and supports their location-based monitoring. The interface is designed to provide laboratory personnel with an immediate overview of the detected assets and their corresponding positions. The Fig.5 presents the system settings interface, through which system-related parameters can be configured. The inventory interface shown in Fig.6 maintains information associated with laboratory assets, enabling users to identify and manage equipment systematically. The Fig.7 presents the history page, which records asset-related activities and provides a traceable record of previous transactions. The notification mechanism shown in Fig.8 further extends the monitoring capability by informing users about relevant asset events. Collectively, these interfaces integrate asset detection with inventory administration, thereby reducing dependence on

separate manual records and improving the accessibility of asset information.



Fig.7. History page

Table.1. Summary of Gathered Result of Real Position vs Scanned Position of Assets and Interpretation of Data using Anova-Single Factor

Asset No.	Location of Asset Real and Scanned Position			
	X: Real Position	Y: Real Position	X: Scanned Position	Y: Scanned Position
A1	4	5	4	5
A2	4	6	4	6
A3	5	9	5	9
A4	11	3	10	3
A5	11	5	11	5
A6	6	2	6	2
A7	4	7	4	7
A8	6	2	6	2
A9	2	5	2	5
A10	5	9	5	8
A11	5	6	5	6
A12	5	7	5	7
A13	6	10	6	10
A14	1	9	1	9
A15	5	6	4	6
A16	7	3	7	3
A17	5	8	5	8
A18	7	3	7	3
A19	3	6	3	6
A20	6	10	6	10

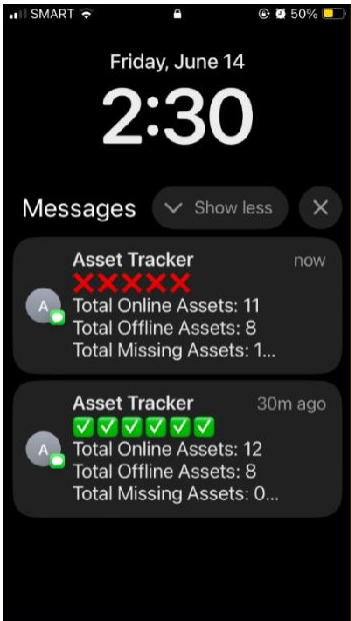


Fig.8. Phone Screenshot of Notification Alert

The Table.1 presents the recorded real and scanned positions of the 20 laboratory assets. The comparison was performed independently along the X and Y dimensions to determine the positional accuracy of the proposed RF tracker. The experimental observations indicate that the scanned coordinates generally follow the corresponding real coordinates, with only small deviations between the measured and actual positions. The average values reported in Table.2 further demonstrate this correspondence. The mean real X coordinate was 5.4, whereas the mean scanned X coordinate was 5.3, representing a difference of only 0.1 coordinate unit. Similarly, the mean real Y coordinate was 6.05, while the mean scanned Y coordinate was 6.0, corresponding to a difference of 0.05 coordinate unit. The relatively small differences between the corresponding means indicate that the proposed tracker can reproduce the approximate physical location of the assets with acceptable consistency.

Table.2. Recorded Results of Real Vs Scanned Position of the Designed Asset Tracker

Groups Y	Count No. of Assets	Sum Σ Assets' Coordinates	Mean (ΣAssets' coordinate)/ No. of assets	Variance
Real X	20	108	5.4	5.9368
Real Y	20	121	6.05	6.6816
Scanned X	20	106	5.3	5.4842
Scanned	20	120	6	6.4211

Source of Variation	Analysis of Variance					
	SS	df	MS	F	P-value	F-crit
Between Groups	9.24	3	3.08	0.5	0.68	2.72
Within Groups	465.95	76	6.13			
Total	475.19	79				

Analysis of Variance shows that the probability value is less than the significance level rejecting the null hypothesis, meaning there are no significant differences between real and scanned positions. It shows that the asset tracker using RF has no significant difference versus the real position of assets.

The Table.3 compares the time required for asset borrowing and returning using the conventional method and the proposed RF-based asset tracker. Under the traditional procedure, the recorded borrowing time was 14 minutes, while returning required 12 minutes, giving a total recorded time of 26 minutes. In comparison, the proposed tracker required 4 minutes for borrowing and 3 minutes for returning, with a reported total of approximately 8 minutes. This represents a substantial reduction in the time required to complete asset transactions. Based on the reported measurements, the borrowing efficiency of the proposed method was 71.43%, while the returning efficiency was 75.00%. The improvement can be attributed to the automated identification and location-monitoring capabilities of the proposed system, which reduce the need for manual searching, record verification, and transaction recording. The system therefore provides a faster workflow for laboratory personnel and users while maintaining an electronic history of asset-related activities.

Table.3. Efficiency Comparison

Method	Time to Borrow	Time to Return	Total time	Efficiency
Traditional	14 min	12 min	26 min	Borrow = 71.43%
Designed Tracker	4 min	3 min	8 min	Return = 75%

4.1 DISCUSSION

The experimental results demonstrate that the proposed RF-based asset tracker can support both asset localization and inventory management within the defined laboratory environment. The small differences between the real and scanned coordinate means indicate that the system provides reasonably consistent localization under the tested conditions. The ANOVA results further support this observation by showing that the measured differences are not statistically significant at the 5% significance level. In addition to localization, the software component provides room monitoring, inventory management, transaction history, configuration, and notification functionality, creating an integrated platform for laboratory asset administration. The efficiency experiment demonstrates another important benefit: the proposed system considerably reduces the time required for borrowing and returning laboratory equipment compared with the manual procedure. However, the results should be interpreted within the scope of the experiment, particularly the 6.5 × 6.5 m laboratory area and the 20 tested assets. Factors such as RF interference, tag orientation, obstacles, greater asset density, and larger laboratory areas may influence localization performance and should be investigated in future experiments. Overall, the findings indicate that integrating RF-based detection with inventory software can provide a practical approach for improving asset visibility, localization, transaction efficiency, and record management in laboratory environments.

The designed asset tracker method significantly reduces the time spent on borrowing and returning assets, resulting in a substantial increase in efficiency. The traditional method requires

manual processes, which are time-consuming and prone to errors. In contrast, the designed asset tracker method automates these processes, ensuring faster and more accuracy.

The researchers developed and evaluated an asset-tracking system specifically designed for an Electronics laboratory. This system utilizes Radio Frequency Identification (RF) technology to enhance asset management and security within the lab environment.

The researchers employed an action research approach, which involves iterative design, implementation, and testing phases. The researchers built a prototype system consisting of RF tags attached to the assets, strategically placed RF readers within the laboratory, and a central software system for data processing and visualization. The system leverages the unique identifiers stored on the RF tags to track the real-time location of each asset. This allows personnel to locate equipment efficiently, potentially reducing search times and streamlining laboratory workflows. Additionally, the real-time tracking capability enhances security by enabling the detection of unauthorized asset movements and providing timely alerts.

To evaluate the system's effectiveness, the researchers conducted a five-trial testing period involving 20 representative assets from the Electronics Lab. The researchers meticulously recorded the actual positions of the assets within the laboratory space and compared them to the locations detected by the RF system. While the system successfully tracked the assets, a statistical analysis using ANOVA (Analysis of Variance) revealed statistically significant deviations between the real and scanned positions. This suggests that the system might not be able to pinpoint the exact location of every asset with perfect accuracy.

5. CONCLUSION AND FUTURE WORK

The overarching aim of this study is to design and develop an Asset Detection Device and Inventory System that leverages Radio Frequency (RF) technology to enhance asset monitoring and inventory management within school laboratories. The successful implementation of this system is expected to significantly make tracking and inventory management for assets more efficient and accurate.

The system demonstrated high accuracy in pinpointing the X and Y coordinates of each asset within the room. Furthermore, this precision is critical for effective asset monitoring, ensuring that each item can be quickly and accurately located. The inventory management system proved to be highly efficient. The automation of asset tracking and inventory updates reduced the time and effort required for inventory management, minimizing errors and enhancing productivity. User feedback highlighted the system's operational efficiency and ease of access. The intuitive interface and user-friendly design ensured that users could quickly adapt to the system, making it an effective tool for daily operations.

6. FUTURE WORK

Future research can focus on extending the proposed RF-based asset tracker to support larger laboratory areas and multiple interconnected rooms while maintaining reliable localization accuracy. The current system can be enhanced by incorporating

advanced RFID/RF readers and multiple sensing nodes to improve coordinate estimation and reduce localization errors caused by interference, obstacles, and tag orientation. Machine learning-based localization techniques can also be investigated to learn environmental characteristics and improve the accuracy of asset-position estimation. The inventory software can be further developed with cloud-based synchronization, mobile application support, role-based access control, and real-time dashboards to enable authorized users to monitor assets remotely. Future versions may incorporate automated alerts for unauthorized asset movement, overdue returns, missing equipment, and assets leaving predefined laboratory boundaries. The system can also be integrated with institutional databases and laboratory booking systems to automatically associate equipment usage with users and scheduled activities. Larger-scale experiments involving more assets, different laboratory layouts, and longer observation periods should be conducted to evaluate scalability and reliability. Finally, future studies can perform a comprehensive evaluation of localization accuracy, energy consumption, communication reliability, scalability, security, and long-term operational cost to establish the suitability of the proposed system for deployment across multiple laboratories and educational institutions.

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