INEXT: A Computer System for Indoor Object Location using RFID

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***Abstract*—The widespread use of the Internet of Things (IoT) has stimulated a growing demand for indoor location systems, given that the Global Positioning System (GPS) may not be efficient or may not work as effectively in such an environment. Radio Frequency Identification (RFID) technology facilitates the construction of low-cost systems for locating and identifying objects. In this study, we propose a computational system that uses passive RFID tags and readers for asset management and control of tagged objects in buildings.**

***Index Terms*—RFID, Indoor Location, IoT**

I. Introduction

Technological advances and interactions with objects (hardware with connectivity capacity) have become increasingly frequent. This approach aims to interconnect objects in a network for interaction and cooperation, potentially changing the way routine activities are carried out. The model for this approach is called the Internet of Things (IoT) [1].

In the IoT, communication occurs among various devices, buildings, or equipment that are equipped with embedded microcontrollers or microprocessors and can connect to networks to facilitate communication with one another [2]. In this context, an approach is proposed for smart cities, which are applications aimed at exchanging information between vehicles, smartphones, traffic lights, and any other devices capable of sending and receiving data [3]. The exchange of data between these devices is intended to improve traffic flow in a city, manage waste, and monitor the quality of life.

The GPS is generally adopted to provide information about an object's position. Nevertheless, its accuracy can be compromised in dense areas and indoor locations [4]. To address the limitations of GPS in areas without a signal, whether due to signal loss or economic constraints, numerous applications have been developed for indoor positioning. These applications employ various technologies, including diffuse infrared technology for position estimation, systems utilizing IEEE 802.11 standard network adapters to track objects inside buildings, systems based on ultrasonic technology, and systems that utilize RFID for indoor tracking [2].

In this sense, the motivation of this research is to assist in locating permanent objects, such as computers and furniture, in environments without relying on GPS, thereby reducing costs [2]. Therefore, this study aims to design and develop an autonomous computational system for inventorying objects using RFID in confined or indoor environments, while employing localization techniques from IoT networks. This approach ensures the reliability of the data location for users to inventory a range of assets.

Outline. In Section II, we discuss indoor location approaches. Section III summarizes related work. In Section IV, we describe the proposed computational system that uses passive RFID readers and tags to manage asset control within buildings. Section V presents the experimental results. Finally, Section VI concludes this paper and describes future work.

II. Background

This section introduces and discusses Indoor Location, including multilateration and proximity.

A. Multilateration for Indoor Location

Location tracking systems require an external infrastructure to locate tagged objects, using smaller and cheaper tagging devices to reduce the computational and power load. Multilateration is a technique that estimates the coordinates of the destination node by considering the distances between the destination node and multiple reference nodes with known coordinates, similar to trilateration. Unlike trilateration, which uses only three reference nodes, multilateration can utilize more than two reference nodes, making it a method that extends trilateration. Adding more reference nodes is intended to enhance accuracy and reduce the size of the uncertainty region [5].

According to Junyi and Jing [5], the calculations are performed as follows: with n reference nodes, which will be represented by R_k, where $k = [1, 2, \ldots, n]$ and each reference node has its already known coordinates (x_k, y_k), and with T representing the target node with unknown coordinates (x, y), we can estimate them using the distance formula, as shown in Eq. (1), of analytical geometry.

$$\begin{cases} r_1^2 = (x - x_1)^2 + (y - y_1)^2 \\ r_2^2 = (x - x_2)^2 + (y - y_2)^2 \\ \quad\quad\ldots \\ r_n^2 = (x - x_n)^2 + (y - y_n)^2 \end{cases} \tag{1}$$

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Then we subtract each of the equations from the first to denote $b_{i1} = \frac{1}{2}(x_1^2 - x_i^2 + y_1^2 - y_i^2 + r_i^2 - r_1^2)$, where $i = [2, 3, ..., n]$ and then linearize the system, as shown in Eq. (2), which can also be written in matrix form $b = AX$. This algorithm requires little computation and is used in many localization systems.

$$\begin{cases} b_{21} = x(x_1 - x_2) + y(y_1 - y_2) \\ b_{31} = x(x_1 - x_3) + y(y_1 - y_3) \\ \quad\quad ... \\ b_{n1} = x(x_1 - x_n) + y(y_1 - y_n) \end{cases} \tag{2}$$

B. Location by Proximity

The proximity technique, according to Bouet and Santos [6], is based on the principle that if the target is within the range of an antenna or reader, its location will be the same as that of the antenna. If the target is within the range of two or more antennas, the location is determined by the one with the strongest signal strength. According to Zhou and Shi [5], when the target is within the range of two or more receivers, centroid calculation is used to estimate the location.

According to Jongchul et al. [7], the proximity technique does not attempt to measure the object's distance from landmarks but determines whether the object is close to one or more known locations. The presence of an object within a given range is usually determined by monitoring range-limited physical phenomena, for example, physical contact with a magnetic scanner, and communication connectivity with access points in a wireless cellular network.

III. Related Work

Jin et al. [2] analyze the method used in the LANDMARC system, which is a localization system utilizing RFID active tags. Reference tags are placed at fixed points in the environment, serving as reference points for system calibration and location. The LANDMARC system equips the readers to detect RFID tags within range. Afterward, weights are assigned to the reference tags based on Received Signal Strength (RSS), with a higher value assigned to the closest ones. The next step involves calculating the Euclidean distance in RSS between a tracking tag and a reference tag. Finally, the system selects the k tags with the smallest values in the calculation and determines the location of the tracking tag. To improve the system, Jin et al. [2] propose the use of only RFID readers and reference tags that reach the target.

Chawla et al. [8] proposed a localization method that allows for estimating the position of objects with speed and accuracy by utilizing the variation of power levels of the readers. This method still relies on reference tags (active tags) to assist in locating the passive tags that will be tracked. The method proposed by Chawla et al. [8] was applied in a room with dimensions of 2m x 3m. The room, resembling a rectangle, was divided into eight sub-regions of equal size called sectors. Each sector was subdivided into four regions of equal size, referred to as quadrants.

In segmenting the environment, Chawla et al. [8] introduced a method employing reference tags placed in each quadrant. Initially, these tags calibrate RFID readers by establishing a power-distance ratio. Subsequently, algorithms adjust the reader's power level, starting from the minimum and gradually increasing it until the object's location is determined. Conversely, the power level can also be adjusted in reverse, starting from the maximum and decreasing it.

Differently from the aforementioned works, the focus of our study is asset management and control of tagged objects within buildings, and not the precise position of the objects.

IV. Proposed Method

This section describes the design and execution flow of INEXT [1], a computational system that uses passive RFID readers and tags to manage asset control within buildings.

A. The INEXT System

The proposed method consists of a system that locates any object considered as part of an organization's heritage. This system includes a passive RFID tag attached to the object's body (see Figure 1). These RFID tags have the ability to communicate with the network to identify and locate objects as they move from one room to another within the building. RFID readers and microcontrollers are installed at the doors of each room, serving as nodes in the network. They are responsible for tracking the location and identification of objects within the building by reading the tags as they pass through the doors. Additionally, a wireless module propagates this information through communication with a web server.

Identifying traceable objects involves two steps: first, attaching passive RFID tags operating at 13.56MHz to each object; and second, using a door device to identify the objects and register their tag's location. Notably, we streamline the registration process by pre-recording RFID tags in the INEXT system app, eliminating the need for the object itself.

The object's location is determined by the proximity algorithm [5]. When the RFID reader identifies a tag, the object's location depends on whether it's associated with a door module. Each module represents a room, so the object's location is defined by the tag-reading device.

The system features a web server (INEXT App) created specifically for this study using the Node.js framework [2] (using several libraries, e.g., Nodemailer was used to send emails from the application, and Mongoose was used to model the objects). This server operates on the same LAN network as the port devices and incorporates a MongoDB database [3] for storing object-related details. Consequently, the web server manages tag reading issues, conducts full inventory surveys, and notifies users of any violations.

In the proposed system, all operations generate logs with the RFID tag's `ID`, `date`, `time`, and `location`. These logs are generated daily. The system also allows for defining constraints on monitored objects. For instance, if an object with a room name in the restriction field leaves that room, the system identifies the violation and sends an email to

[1]https://github.com/luarkian/nodeArd-INEXT.git
[2]https://nodejs.org/en/download/
[3]https://www.mongodb.com/download-center/community

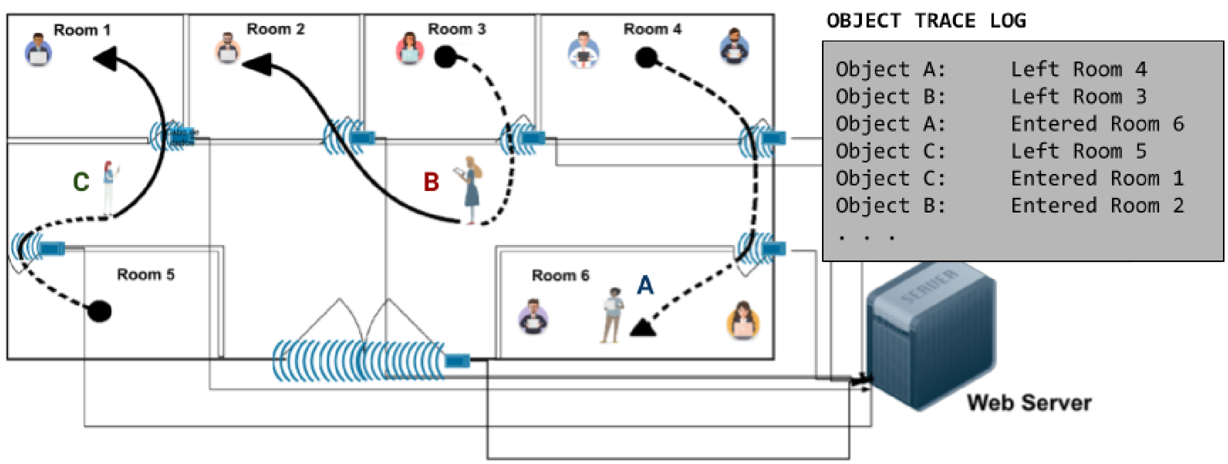

Fig. 1. Overview of the proposed method.

administrators with the object's data. This feature is crucial for objects that must remain in a specific room and ensures better management and tracking.

Communication in the system occurs via WLAN, requiring all devices to be on the same local network. However, communication is only between door devices and the server; there's no direct communication between door devices. For this purpose, we used the NodeMcu ESP-12E board as a prototype proposal. The board, detailed in its datasheet [4], features an ESP-8266 module, enabling wireless network connectivity through the 802.11 b/g/n standard, supporting speeds up to 300 Mbps in the 2.4 GHz or 5 GHz spectrum.

Room door devices, when reading a tag, generate a JSON object that contains the name of the room and the identification of the RFID tag (e.g., `566C96A5`). After the object is created, it is sent to the server via a POST request to perform operations and modify the status of the object attached to the tag.

The prototype in this study, referred to as the door device, consists of a NodeMcu board and an RC522 Mifare RFID reader operating at 13.56 MHz [5]. It's worth noting that this prototype is designed for system evaluation, and the RFID reader can easily be replaced with one that offers a longer tag-reading range. The RFID reader communicates with the NodeMcu using the SPI interface (Serial Peripheral Interface).

V. Experimental Evaluation

This section presents the planning, execution, and analysis of the results to evaluate the proposed system.

A. Planning and Design of The Experiments

The experimental evaluation aims to validate INEXT for object identification, indoor location, and subsequent management. Thus, we pose the following research questions:

RQ1 : Can the INEXT system identify and track objects in a confined scope?

[4]https://www.electrodragon.com/w/ESP-12F_ESP8266_Wifi_Board

[5]https://www.nxp.com/docs/en/data-sheet/MFRC522.pdf

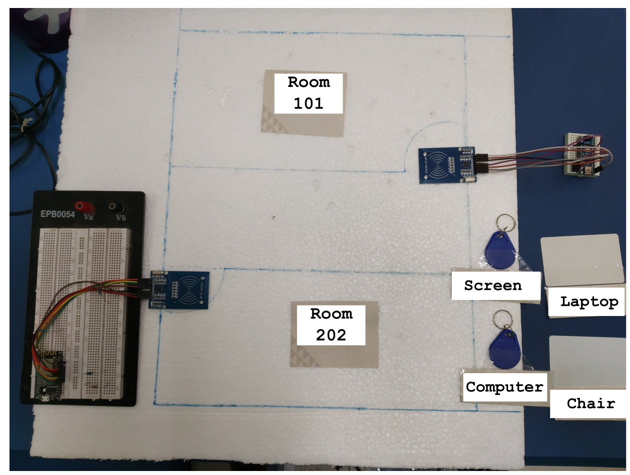

Fig. 2. Simulation Scenario

RQ2 : What advantages does the INEXT system provide regarding the management of objects in buildings?

RQ3 : Is the INEXT system capable of automatically generating the inventory of objects in a confined area?

To address these research questions, we simulated two rooms using the Arduino Nano V3.0 ATmega168, RFID reader RC522, and a NodeMcu ESP-12E board. However, an Arduino was connected to a computer via the serial port. Due to the lack of a second NodeMcu board for wireless communication, we employed a Python script (v3.7.1) to read serial port data, generate a JSON object, and transmit it to the server. We have adopted a computer as a web server with 4GB of RAM, an Intel Core i5 processor, a 500GB HDD, and it runs on a 64-bit system. The LAN network was created using a TP-LINK router model TL-WR720N. We are using four passive RFID tags, each representing a different object for the simulation. We have defined the scenario shown in Figure 2, simulating two rooms and four traceable objects in a building.

B. Execution of the Experiments

To address the research questions in the experimental planning, we conducted **Test (1)** in the experimental scenario. This test involved registering four tags in the system as distinct objects. Two tags were positioned near room 101's door, and the other two near room 202's door. The registration process was repeated three more times, affirming the system's registration capacity.

In **Test (2)** of the experimental scenario, two users were created to be notified (via email) when there is a transition of the objects between rooms. To accomplish this, we utilized webmail services like Gmail and Outlook. Transitions were performed for all objects with constraints. In **Test (3)**, all objects monitored (the inventory) by the INEXT system are surveyed in their respective rooms.

C. Results Analysis

After conducting the tests, we summarize the results in Table I, with each row representing an execution scenario and its corresponding counts: instances where the INEXT system worked flawlessly (**It worked**), situations where it had partial success (**Partially**), and cases where it failed to deliver the expected result (**Failed**).

TABLE I
RESULTS

	Number of tests	**It worked**	**Partially**	**Failed**
Test 1	8	7	-	1
Test 2	8	8	-	-
Test 3	7	6	1	-

INEXT was able to locate objects tracked by RFID in confined environments. However, the proposed system does not provide the specific position of the object in the environment, e.g., 3 meters from the right side of the room. INEXT was also able to identify the objects, but this initial step still occurs manually, requiring users to edit the objects in the system after registering them. During the tests, there was one instance where the script crashed due to a USB cable disconnection.

During the first attempt to generate the inventory of objects registered in the system, there was data repetition in the database. This problem can be solved by the user accessing the Room Management screen and removing the duplicated rooms (i.e., the system was unable to identify the duplicates). In this manner, the generation of the inventory worked without the repetition of objects and rooms. To obtain a better evaluation of the system, we conducted a questionnaire consisting of three questions that were given to three people who were or are coordinators/heads responsible for managing assets in the departments of Federal University of Roraima (UFRR) courses. The questions are listed below:

1) From 0 to 10, do you think the system can help manage university assets?
2) On a scale from 0 to 10, what grade would you give to evaluate this solution as applied to the problem?
3) From 0 to 10, what is the probability of recommending the system to UFRR employees who carry out asset management and survey tasks?

In the previous questions, we have defined a quantitative representation, as follows: 0 and 1 are very bad, 2 and 3 are bad, 5 and 6 are reasonable, 7 and 8 are good, and 9 and 10 are very good. The questionnaire result is shown in Table II.

TABLE II
DATA COLLECTED FROM THE QUESTIONNAIRE CARRIED OUT

	Person 1	**Person 2**	**Person 3**	**Average**
Question 1	10	9	10	9.66
Question 2	8	8	7	7.66
Question 3	9	9	10	9.33

The average of the answers to Question 1 is 9.66. This demonstrates that if implemented, the system can assist in managing and surveying university assets. It facilitates the current survey process, where an employee is required to visit all rooms, check them, and document all references to the objects found there.

In question number 2, the answers had an average of 7.66, which shows that the resulting system presented significant results. However, the proposed system is not capable of solving all problems. For instance, when the object is in transition and does not enter another room, it will not have a location within the system. Finally, question number 3 obtained an average of 9.33, which generally shows that the system has great potential for applicability in real tests at UFRR and for analysis by the employees who perform this function.

VI. CONCLUSION AND FUTURE WORKS

This study proposes a computational system called INEXT for locating and identifying objects in buildings using radiofrequency, specifically passive RFID tags. The conducted experiments indicate promising results. It was possible to identify instances of violating constraints on object movement and report them to the respective administrators. In future work, we aim to improve the location of objects; for example, active tags can be used to assist in the process, providing greater accuracy in locating objects within the environment.

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