Smart Inventory Management System with RFID and Real Time IoT Integration

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**Abstract.** The escalating popularity of online shopping in this day and age has placed greater pressure on the relevant parties that are responsible for managing the inventory. The utilization of conventional inventory handling techniques, such as barcode scanners in handling stock in previous research, has demonstrated inefficiency, low accuracy, and lack of automation of the inventory management system. This study aims to come out with an efficient and accurate solution that offers precise stock tracking and automates the inventory handling process. As a result, the integration of cutting-edge technologies like Radio Frequency Identification (RFID) and the Internet of Things (IoT) into the inventory management system is anticipated to cope with the challenges confronted by enhancing the accuracy, efficiency, automation, and real-time tracking. Incorporating RFID readers and IoT sensors prevents the system from stockouts and overstocks and is able to provide real-time visibility into inventories’ movement and stock level. Overall, the findings suggest that adopting RFID and IoT technologies can significantly enhance inventory management efficiency, accuracy, and scalability.

# INTRODUCTION

In our daily lives, the selling and buying process occurs every second. The goods that the consumers purchase undergo several processes to be distributed, delivered, and arranged on the shelves in stores after being manufactured by the factories. In this context, the inventory management system embedded in warehouses and retail stores often plays a critical role in the product distribution process to ensure efficiency in tracking, storing, and distributing goods.

Most inventory management systems today rely on manual systems such as barcode scanners to handle their inventory. Nevertheless, human error, overstocking, and inventory discrepancies may occur. As a consequence, we can say that the inventory management systems fail to demonstrate effectiveness and accuracy in handling goods. This statement is supported by the statistics showcasing that 74% of the businesses in Malaysia have encountered severe stock outages and overstocks due to the nature of the barcode scanners, which require substantial labour efforts and offer limited automation [3]. Therefore, the “Smart Inventory Management System with Radio Frequency Identification (RFID) and Real-Time Internet of Things (IoT) Integration” that is named IoTventory is designed to address the aforementioned challenges. This is because it allows higher efficiency in tracking the stock level and identifying identical product batches by combining advanced technologies to optimize inventory processes.

The employment of RFID technology and IoT sensors in IoTventory allows for precise and quick tracking, reduces manual intervention, and improves decision-making for inventory control. This is due to the capability of RFID that identifies and tracks stock rapidly, IoT sensors that provide real-time updates, and a mobile application to push notifications to remind the relevant authority of the stock level updates. The successful integration between RFID, IoT devices, and mobile applications makes an accurate and automatic inventory management system.

The goal of this research is to develop a smart inventory management system - *IoTventory*, a mobile application that provides precise stock tracking with the employment of RFID and IoT sensors. Besides that, it should have the ability to automate the inventory handling process and send instant notifications.

This research is guided by the following research questions:

1. How does the employment of RFID and IoT in inventory management systems enhance accuracy and efficiency compared to conventional barcode systems?
2. What are the performance metrics of the proposed system in terms of accuracy, latency, and error rates in comparison to traditional barcode-based systems?

# RELATED WORK

The Internet of Things (IoT) has been a hot topic for all and sundry because of its widespread use across various sectors and areas, including supply chain, construction, fashion, food and beverage (F&B), and so forth.

For Kiruthika et al. [4], the researchers suggest handling inventory in retail or kitchen settings using an IoT-based system. The load cells are located underneath the grocery containers to measure the weight of the goods; changes in weight or stock levels can be updated instantly to the cloud, and the user is notified when they fall below the threshold. However, this system is primarily applicable to static environments such as kitchens or small retail stores and is not scalable to larger, more dynamic inventories. Unlike this system, IoTventory allows for dynamic inventory sizes, ranging from small retail stores to large distribution centres, as the quantity of RFIDs and the load cells may be easily added or removed depending on the size of the inventory space.

Rajesh Bose et al. [5] proposed an inventory management system that integrated IoT, cloud computing, and barcode technology customised for the construction industry. This system is designed to address inefficiencies in managing construction materials. It allows inventory tracking from deployment to resizing and disposal, aside from real-time data updates. All the data in the system can be protected by digesting authentication and encryption. The system relies heavily on manual processes, such as affixing barcodes and updating inventory records, which would require intensive labour and slow down the inventory handling process. It is necessary to build the proposed IoTventory by transforming the manual work into full automation, such as RFID-based systems, to reduce manual effort and errors.

Shweta Pethe et al. [7] focus on integrating IoT technologies such as GPS trackers, RFID tags, and sensors in supply chain management and logistics, which helps in real-time inventory tracking. The efficiency of the shipment and production can be ensured because it is all tracked and monitored by the central system, so the bottlenecks can be detected as soon as possible. From a different perspective, the large volume of data generated by the IoT devices requires advanced tools for storage, processing, and analysis to avoid system downtime.

On the other hand, Saillaja et al. [8] developed an inventory system for retail stores that employ IoT-enabled sensors such as RFID tags, Bluetooth beacons, and cameras to provide real-time insights into stock levels and customer behaviours. For instance, the Bluetooth beacons monitor the customer and product movement within the store, identifying goods placement and customer interaction. Integrating the aforementioned IoT-enabled sensors requires a high initial setup cost, which may be a barrier for small retailers. In contrast, IoTventory is considered small and medium-sized enterprise (SME) friendly because it allows users to scale the number of RFID scanners and IoT sensors according to their budget. Lower-cost RFID scanners can be deployed for smaller setups, while higher-coverage options are available for larger installations.

In summary, IoTventory, which combines RFID and IoT, builds on these proposed works by addressing the research gaps, like the low accuracy of manual inventory management systems, unscalable solutions, and expensive startup costs.

# PROPOSED METHODOLOGY

The designated inventory management system incorporates React Native for frontend mobile application development, Firebase Realtime Database, RFID, and also IoT to ensure smooth operations. Figure 1 showcases the system design diagram that illustrates the interaction between the user layer, RFID layer, and the backend infrastructure (web and database server) over the internet.

First and foremost, the user layer. The main users of the system are targeted as inventory managers, staff, and suppliers. They will access the system through the mobile application with internet connection availability, which is hosted by the web server. The web server is in charge of receiving end users’ requests, processing them, and sending back the appropriate responses. It also communicates with the database server to retrieve or store data in real-time to ensure that the information across the system is up-to-date.

Next, the IoT layer, which consists of IoT sensors and a gateway. The weight sensors are used to constantly monitor the weight changes of the inventory. While, the IoT gateway serves as the bridge that transmits the data gathered by the sensors to the database via the internet for processing. Therefore, the system is able to send alerts to the users immediately when there is low stock or unauthorized movement of the inventory.

Besides that, the RFID layer. It is built up with RFID tags, a reader, and middleware. Each item will be assigned an RFID tag that indicates its unique identity. The data of the item that is attached with an RFID tag can be scanned by the RFID reader to capture its information. It is useful when detecting the movement of the inventory, and it will be updated automatically to the system with the help of RFID middleware. It processes data from RFID readers before sending it to the system.

The database server, Firebase Realtime Database, is another crucial element in the inventory management system to support all the system backend data storage and retrieval.

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**FIGURE 1.** System design diagram

## PROCESS FLOW

Understanding how the proposed smart inventory management system works steps-by-step is crucial, as it involves complex communications between the mobile application, RFID, and IoT sensors, particularly for the stock-in and stock-out processes.

Figure 2 illustrates the process flow diagram when the item is stocked in. The fixed RFID reader that is installed on the wall is responsible for scanning the RFID tags that are attached to the items when they are moved into the warehouse. It will check if the RFID unique ID already exists in the database, and if so, an error message will be displayed to show that the RFID tag is already registered in the system. Otherwise, it will check again with the item’s barcode to see if it exists in the database. If there is no particular item’s barcode in the system, it will direct the staff or inventory manager to add it into the system. On the other hand, if the item’s barcode can be found in the system, which means it already has a record in the system but with different batches, then the user will be prompted by an add batch form. Then, it will save the batch details along with the unique ID of the scanned RFID tag after the user has successfully submitted the add batch form.

Figure 3 demonstrates the process flow diagram when the item is stocked out. The fixed RFID reader will scan the RFID tags that are attached to the items every time they pass by the entrance or exit. It will determine whether the database has the RFID unique ID. The system will display error messages to indicate there is no RFID tag found when the RFID unique ID cannot be found in the system. The system first retrieves the batches and item’s details while the RFID unique ID can be found in the system, then deducts the stock quantity, and finally updates the inventory quantity in the database. The user will be notified when the current stock level falls below the predetermined minimum stock level so that further action can be taken.

The load cells get involved in the process when the inventory is put on and removed from the shelf. It is responsible for monitoring the change in inventory weight continuously. The weight data is preprocessed by an IoT module that is connected to each load cell before being sent to the IoT gateway. The notification will be sent to the user when any stock additions and removals are detected and double-checked with the scanned data from the RFID readers at the entry and exit points.

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|  | A screenshot of a phone  AI-generated content may be incorrect. |
| **FIGURE 2.** Stock-in process flow diagram | **FIGURE 3.** Stock-in process flow diagram |

# PROTOTYPE AND UI DESIGN

IoTventory offers users a myriad of features, from the most basic to the most advanced. This includes the sign-up, sign-in, CRUD capabilities for inventories, orders, suppliers, IoT sensors, reports, and so on and so forth. We will discuss multiple system features in more detail later.

Figure 4 shows how the system interface will look when displaying the inventory listings. The user, such as inventory manager and staff can perform several tasks on this screen, like viewing the item’s details, editing, deleting, or even adding new items to the system. Furthermore, Figure 5 depicts the screen where all the notifications will be displayed. The user will be informed whenever the stock levels are low, an item is about to expire, or it is relocated. Figure 6 demonstrates the prototype of the IoT sensor listings screen. It allows the user to obtain information regarding the specific weight sensors used, such as the item it monitors, the weight change detected, its location, and others. Figure 7 is another example of showing the RFID tag listings. The details, like the item that owns the particular RFID tag, its batch number, and also the last scanned timestamp, will be shown. Besides that, it supports CRUD operations without a doubt. Apart from that, the user may easily browse the system to find the information they need since every detail will be displayed on dedicated screens. However, the system implements role-based access control, meaning that only a certain role may utilize certain functions. As an illustration, the inventory manager or management is able to add a supplier to the system, while the staff is unable to perform the task.

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| **FIGURE 4.** Inventory listings | **FIGURE 5.** Notifications push |

# SYSTEM EVALUATION

In order to evaluate the performance of the system from different aspects, which includes accuracy, latency, and error rate, a controlled simulation was set up to replicate the warehouse operations that involve stock in and stock out. It was constructed using the following hardware components:

* PN532 RFID readers placed at entry and exit points,
* ESP32 microcontroller for real-time processing
* 5 kg capacity load cells with HX711 load amplifier to monitor the item’s weight

The configuration was chosen for its low cost and flexibility. However, large-scale environments can select RFID readers that cover a wider range. For example, the Zebra FX9600 Fixed RFID reader can be used in large-scale warehouse operations, as it offers a 10+ meter read range.

Several testing scenarios were conducted using a variety of datasets with different items’ weights, expiry dates, and movement types. For instance, detection accuracy was measured by tracking the precise number of inventories entering and exiting the simulation warehouse. Moving on, monitoring how long the time needed to update the database when the item is scanned by the RFID readers gives a clearer picture of how well the system performs. Next, error rate is the percentage when there are missed scans and incorrect stock deductions.

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| **FIGURE 6.** IoT sensor listings | **FIGURE 7.** RFID tag listings |

As a result, IoTventory achieved an inventory tracking accuracy of 98.5%, significantly higher than the typical 80-90% accuracy observed in the manual barcode scanning systems. Other than that, it is observed that an average latency of under 2 seconds for the real-time stock level updates. This is much lower than the barcode-based systems, where updates can be delayed for hours. The proposed inventory management system stands out from the manual scanning reliance systems for its low error rate of only 1.5%, as barcode-based systems can have high error rates due to human errors.

Table 1 reveals the comparison between IoTventory and the traditional barcode-based inventory management systems in multiple aspects, including manual input time, automation level, and setup cost. The traditional barcode system takes longer to manually input the item details because there is less automation given, which IoTventory performed better in these areas. However, the traditional barcode systems are less expensive to set up than IoTventory, where RFID readers might be costly if wide coverage is required.

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| **TABLE 1.** Comparison between IoTventory and traditional barcode system | | |
| **Metrics** | **Traditional barcode system** | **IoTventory** |
| Manual Input Time | High | Low |
| Automation Level | Low | High |
| Setup Cost | Low | Medium |

# CONCLUSION and future work

This paper has presented a smart inventory management system, called IoTventory, that employs cutting-edge technologies like RFID and IoT to streamline the inventory handling process. The combination of RFID and IoT distinguishes the proposed system from the current market systems because it promotes automated inventory management, which significantly reduces the possibility of stock outages and overstocks, even when there are only a few staff. In the meanwhile, the ability to track the weight and batch of the goods is a good example of showcasing how the system’s accuracy and efficiency have improved. IoTventory software offers an intuitive and attractive user interface that comes with a variety of useful features, such as stock movement tracking, a batch tracking module, real-time notifications, and others. However, it is feasible to improve the system by expanding its capabilities with machine learning for predictive analytics on stock levels and offline functionality to ensure uninterrupted operation in the future. We believe that a more sophisticated, improved, and scalable version of the smart inventory management system can continue adapting to the demands of various industries with continuous refinement and evolution.

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