PalArch's Journal of Archaeology of Egypt / Egyptology

IMPLEMENTATION OF ZIGBEE-ENABLED RFID INVENTORY MANAGEMENT SYSTEM IN RETAIL STORES

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Grace Ong, Intan Farhana Binti Kamsin. Implementation of Zigbee-enabled RFID Inventory Management System in Retail Stores-- Palarch's Journal of Archaeology of Egypt/Egyptology 17(7), 8699-8708. ISSN 1567-214x.

Index Terms: Internet of Thing, IoT, Zigbee, RFID sensor network, inventory tracking, IRI.

ABSTRACT:
Inventory record inaccuracy (IRI) issues are prevalent across the retail industries. In recent years, Radio Frequency Identification (RFID) technology has been considered as a promising solution for IRI and is widely implemented across the retail stores. However, most of the RFID solutions are based on recording the input and output of the inventories to provide a stock situation. In this paper, an effective IoT solution based on the real-time visibility of the inventory items is proposed to solve the IRI issues of fashion retail stores. Firstly, surveys and literature reviews on fashion retail stores will be carried out to further understand the factors generating inventory record inaccuracy. Secondly, a prototype of the proposed solution will be built to evaluate its reliability, efficiency, effectiveness, and security. Finally, the implementation of the corresponding potential solutions is suggested along the supply chain for better information flow of the inventories.

INTRODUCTION

As the field of management and business operations becoming more competitive in recent years, the development of a new inventory management system has been increasingly interested among the retail companies. Most of the retail companies re-examine their inventory management system to identify the opportunity for any improvements to stay competitive in business operations. According to [1], having accurate inventory records in the inventory management system is crucial to the business performance and maintenance of the retail companies as it will affect the decision making on

forecasting demand and inventory replenishment. A study by Rekik et al. [2] reported that an average of 54.8% of the audited stoke-keeping units (SKUs) in the fashion retail stores, the inventory records in the inventory management system did not match with the actual physical inventories. These discrepancies can cause excess inventory, leading to incurring of extra costs [3]

This paper proposes a new inventory management system based on IoT technology such as radio frequency identification (RFID) technology and Zigbee wireless network for identifying the real-time localisation of the inventories to reduce inventory record inaccuracy (IRI) issues. This research describes the study and the development of an automatic real-time inventory tracking system for a typical fashion retail store which had been chosen to be the case study in this research. Firstly, a case study in the fashion retail stores will be carried out to understand the problems in managing inventories. Then, a new RFID inventory management system integrated with a Zigbee wireless network will be developed to overcome these issues and provide better inventory control. Finally, a pilot test will be conducted to evaluate the performance of the proposed system in terms of its effectiveness, efficiency, security and reliability.

RESEARCH BACKGROUND

Inventory Management System (IMS)

An inventory management system (IMS) is the combination of technology in terms of both software and hardware with operational processes and procedures, that supervises the maintenance and monitoring of stocked products [4]. A typical inventory management system consists of the following features [5].

1. A system that can identify each inventory and its associated information, such as asset tags, barcode, or RFID labels.
2. Hardware tools that can read the RFID tags or barcode labels on the stocks such as handheld scanners.
3. Software tools that can provide central monitoring of the inventory, including managing the inventory database, generating inventory analysis report, forecasting future demand and so on.

Internet of Things (IoT) in Retail Industry

The development of the Internet of Things technology has shown an increasing trend in the areas of retail, security and product management in recent years [6]. This circumstance is because the main enabling capabilities of IoT such as regular sensing, data collection and actuation allows new approaches to improve the process of product maintenance and establish long-lasting connections with clients [7]. The two leading widely used IoT technologies used in the retail industry are RFID and Zigbee wireless sensor network [8].

1. Radio Frequency Identification (RFID)

Radiofrequency identification (RFID) is one of the standard automatic identification and data collection (AIDC) technologies used in the inventory management system. It is a contactless information transmission technology

that allows automatic identification and tracking of inventories without a line of sight [9]. A typical RFID inventory management system consists of three elements: RFID tags, RFID readers and a software system that can record the information of the inventories.

RFID tags can be classified into two categories: active and passive. A comparison table between active RFID and passive RFID in details is shown below.

Table 2.1 Comparison table of active RFID and passive RFID [10]

Features	**Active RFID**	**Passive RFID**
Frequency	244 MHZ, 2.45GHz	860-960 MHz
Read Range	150m	15m
Cost	$20 - $50/unit	< $1/bag
Tag Size	Smaller than a smartphone	Smaller than a business card
Asset Size	Medium to very large	Very small to very large
Industry	Construction, Oil, Gas, Mining	Retail, Healthcare, Manufacturing
Location	Outdoor Application	Indoor/Outdoor Application
Attachment Method	Rivets, Screws, Zip Ties, Welding	Hanging, Epoxy, Adhesives, Zip Tie, Welding
Power	Internal Battery	Powered by RF waves from readers
Drawback	Batteries only last 3 – 5 years and typically cannot be changed	Less effective around metal and water

RFID tags also operate in a different range of frequencies. Different frequency ranges will determine the performance of the RFID tags such as their resistance to interference [9]. Passive ultra-high frequency (UHF) RFID tags is the preferable choice in the inventory management system as it can perform multiple read rates, allowing it to identify many tags at a time [9]. Passive UHF RFID tags can also be printed directly onto the inventories with the use of inject-printing technology, which further decrease the cost [11].

2. Zigbee Wireless Network

Zigbee is a wireless communication standard built on the media access control and physical layer in the IEEE 802.15.4 that features low-power, cost-effective, reliable, products controlling and wirelessly networked monitoring [12]. Since IEEE 802.15.14 supports most of the communication components, Zigbee can perform excellent peer-to-peer communication. Zigbee is also known as a sensor network standard which allows up to 65535 nodes in a single network. It has self-healing and self-organizing network structure that can provide multi-hop and routing functions to the packet-based radio protocol [13]. Besides that, Zigbee can be used to estimate the coordinate of a target based on the Received Signal Strength Indication (RSSI) [14].

Barcode IMS Vs RFID IMS

In this section, two inventory management systems, barcode IMS and RFID IMS will be discussed and analysed in terms of their integration capability with IoT technology to facilitate real-time tracking and localisation of the

inventories. Figure 1 shows the process of updating the inventories into the IMS database by scanning each of the inventories manually in a barcode IMS.

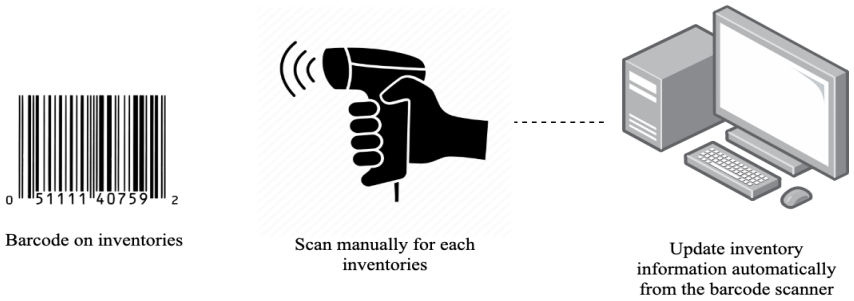

Figure 2.1 Barcode inventory management system

Figure 2 shows the process of updating the inventories into the IMS database by scanning a batch of inventories at a time in an RFID IMS.

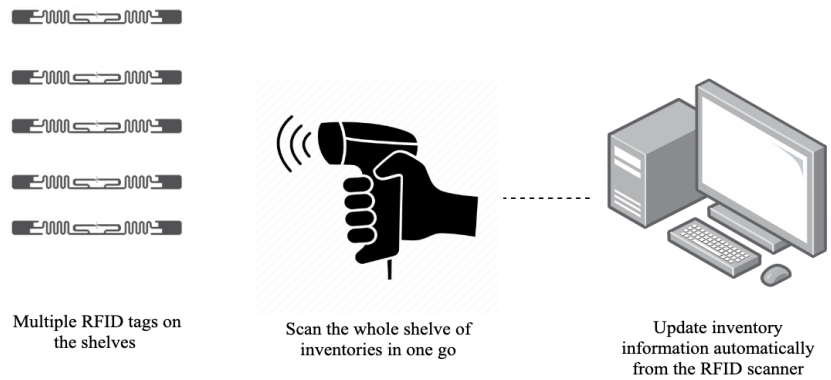

Figure 2.2 RFID inventory management system

According to both Figure 1 and Figure 2, both IMSs serve the purpose of recording the inventories into the system. However, IRI issues can still occur due to execution errors. For example, some of the stocks might get left out during the scanning process. To further understand the characteristics and features of these systems, a comparison between barcode IMS and RFID IMS in details is shown below.

Table 2.2 Comparison table of barcode IMS and RFID IMS [15], [16]

Features	Barcode IMS	RFID IMS
Line of sight	Required	Not required
Read/Write capability	No	Yes
Read Rate	Very low throughput. Tags can only be read manually, and one at a time	High throughput. Multiple (>100) can be read simultaneously
Security level	Low. Easily damaged or removed. Cannot be read if greasy or dirty	High. Difficult to replicate. Information stored in a much more secure environment
Tag Information Storage	< 100 char (1D) < 2000 char (2D)	256 bits
Real-time tracking capability	No	Yes

Localisation capability	No	No
Event Triggering capability	No	Yes
Deployment Cost	$100,400	$109,200

According to the table above, barcode IMS cannot integrate with IoT technology as it will disable the sensing feature due to its incapability to trigger an event. Although RFID IMS is better than barcode IMS in overall, the scanning of the inventories only occurs during the input and output of the inventories. Both barcode IMS and RFID IMS cannot ensure an accurate inventory record in IMS until the workers perform stocktaking.

Therefore, this paper proposes a solution that is capable to detect the real-time location of the inventories with the integration of Zigbee wireless network in an RFID IMS. The proposed solution can be further enhanced with the implementation of RFID sensors on the shelves to enable real-time tracking. An illustration of the proposed system is shown below.

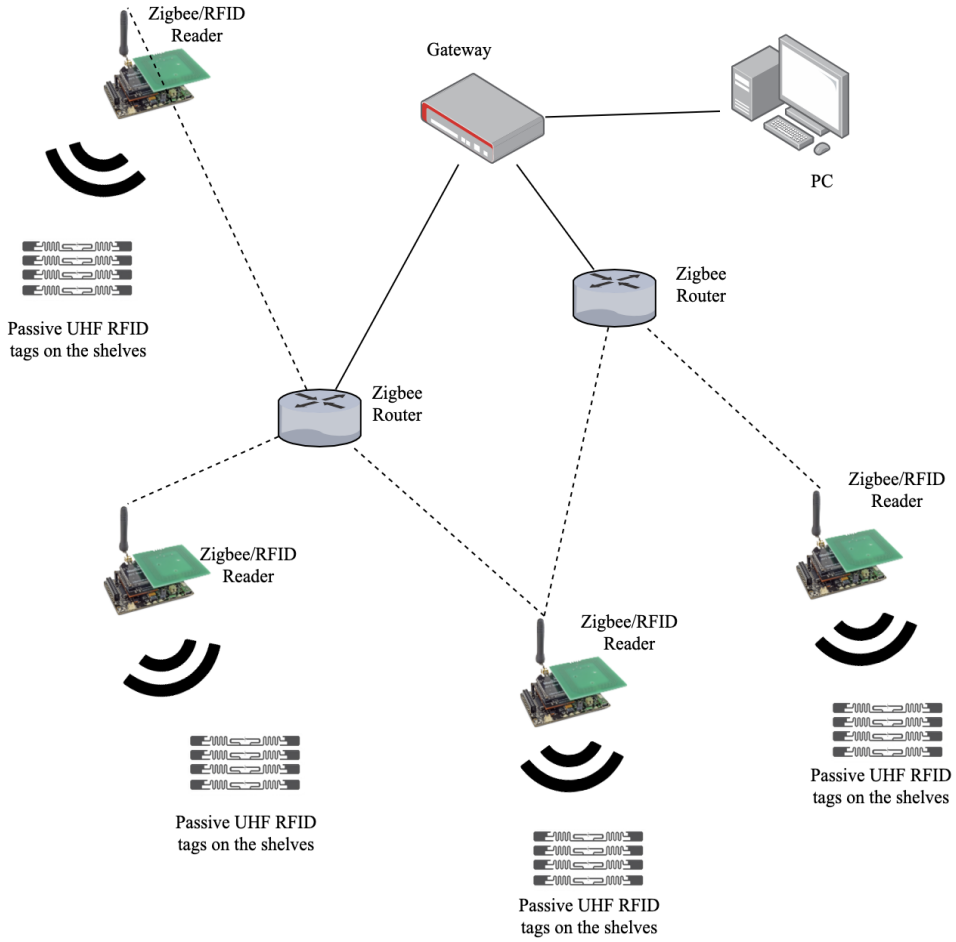

Figure 2.3 Zigbee-enabled RFID IMS

PROBLEM STATEMENT

Inventory record inaccuracy (IRI) has always been a significant operational issue in the retail supply chain that indirectly affects financial performance [17]. IRI may stem from multiple factors such as transaction errors, misplacement errors, and shrinkage[18]. Rekik et al. [19] reported that

shrinkage including spoilage or theft is the main factor generating negative discrepancies between the actual physical inventory level and the inventory record in the inventory management system (IMS). Since the inventory shrinkage can be translated as permanent item loss, this phenomenon can cause an accumulation of discrepancies over time. If the shrinkage problem is not corrected, the situation will cause the automatic inventory replenishments in the IMS to be made too late, increasing the stockout risk which leads to more sales loss over time [2]. Several attempts had been made by most of the retail stores to solve IRI issues. For example, retail stores will spend almost 10% of the sales on extra labour expenses to perform a more regular stocktake [20]. However, this solution will diminish the profit and also defeat the purpose of using an inventory management system to forecast demand and replenish the inventory automatically. According to Fan et al. [17], Radio frequency identification (RFID) technology has the potential to eliminate shrinkage problems. However, the current available RFID inventory management system in the market can only provide the inventory situation based on recording the inventory during input and output which technically cannot reduce shrinkage problems [21]. Therefore, investigating another approach of solving IRI issues using the Internet of Things (IoT) technology in providing real-time visibility of the inventory will have practical benefits to the retail stores.

AIMS AND OBJECTIVES

This research aims to propose an effective IoT solution to solve the inventory record inaccuracy issues of fashion retail stores by focusing on the following specific objectives:

1. To implement an RFID inventory management system in the fashion retail stores such as Uniqlo to improve IRI.
2. To enable real-time tracking of inventories.
3. To enable localisation of the inventories.

RESEARCH QUESTIONS

1. How RFID inventory management system improves the inventory accuracy of a retail store?
2. How the deployment of multiple RFID sensors on the shelves of retail stores enable the real-time tracking of the inventories?
3. How the integration of Zigbee wireless network with RFID inventory management system achieve the localisation of the inventories?

SIGNIFICANCE OF THE WORK

The findings of this research will redound to the benefit of retail sectors and supply chains, understanding that inventory record inaccuracy plays an essential role in financial performance. The higher the demand on inventory management system in providing accurate inventory record for forecasting demand and automatic replenishment justify the need for solving the IRI issues in a more practical approach. Thus, retail stores that apply the recommended IoT solution derived from the result of this research will be able to reduce the IRI issues of the retail store. Managers of the retail stores will be guided on how to use the new proposed system so the workers can fully utilise

the potential of the inventory management system in managing and monitoring the inventories in the retail stores. For the researchers, the study will help them uncover the potential in using IoT technology to solve IRI issues practically that many researchers were not able to explore. Thus, a new inventory management system on solving IRI issues may arrive.

METHODOLOGY

This research will use both quantitative and qualitative research approaches to study an in-depth exploration of the factors causing inventory record inaccuracy in fashion retail stores. A survey that consists of 5 multiple choice questions and 10 questions with 10-point Likert scales about the current inventory management system installed will be given to the manager of the retail store. This survey will be conducted with 15 retail managers of Uniqlo registered around Kuala Lumpur. The quantitative data generated from this survey will be monitored first to eliminate missing data and outliers. The data will then be analysed using descriptive statistics including mean, mode and percentage distribution. Besides that, a literature review on the causes of inventory record inaccuracy from both primary and secondary data will be conducted to help in understanding the behaviours of the data collected in the survey. Transcription of the quantitative data collected in the survey will be reported later.

After that, the quantitative experimental study will be used to evaluate the feasibility of RFID inventory management system in tracking the inventories in real-time and enabling the localisation of inventories. A prototype will be built based on the RFID inventory management system. The environment of the fashion retail store will be replicated in a laboratory with the deployment of UHF RFID tags on each inventory and RFID sensors on the shelves. Theses setups are crucial to mimic the real-world situation of a fashion retail store. Afterwards, the effectiveness of the whole prototype system on detecting the physical inventory level in real-time will be validated by comparing information received from the RFID sensors with the actual inventory level and the consistency of the information received continuously. Then, a Zigbee wireless network will be integrated into this prototype system to investigate its feasibility in achieving localisation of the inventories. The localisation of the inventory feature will then be evaluated on its consistency of providing accurate coordinates of the inventories in the shelves. The quantitative data generated will be further analysed using descriptive statistics. Multiple regression will also be used to explain the relationship between the independent and dependent variable. Although a lab-based experiment with the implementation of a prototype cannot completely simulate the real-world situation and behaviours, it helps in testing the minimum feasibility requirements of the proposed system effectively.

OVERVIEW OF THE PROPOSED SYSTEM

In this section, an overview of the proposed RFID IMS with a Zigbee-enabled wireless network will be discussed. A user-diagram of the proposed system is shown above. According to the user-diagram, the basic features of IMS will be implemented in this proposed system such as user administration, inventory management, inventory level checking, future inventory demand forecasting,

report generation and automatic inventory replenishment according to the inventory records. The new feature that is included in the proposed system is inventory coordinate checking. The coordinates of a particular inventory will be shown in the IMS according to the location of the shelves, columns and rows. The inventory records can be refreshed by just clicking a button in IMS to activate the scanning of all RFID tags on the inventories after the implementation of Zigbee-RFID readers on each of the shelves of the fashion retail stores. Hence, this feature can fully replace the manual stocktaking process and ensure that the inventory records in the IMS match the actual physical inventories in the fashion retail store.

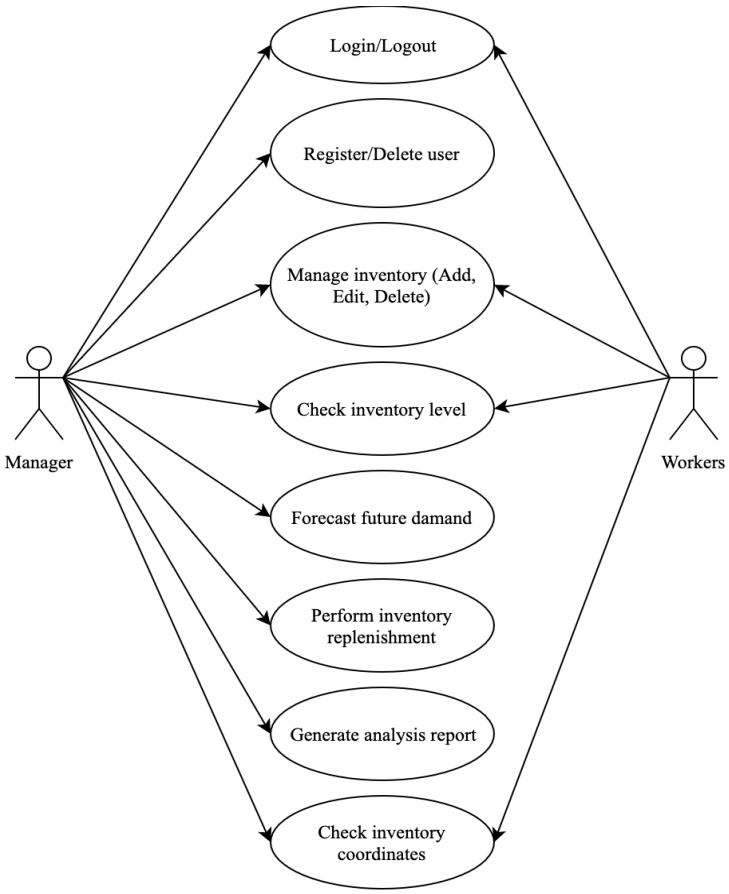

Figure 8.1 Use-case diagram of Zigbee-enabled RFID IMS

CONCLUSION

This paper proposed integration of Zigbee wireless network with the RFID inventory management system to solve inventory record inaccuracy issues. By identifying the location of the inventories in real-time, it not only able to maintain an accurate inventory record in the inventory management system but also supports the users to track the physical location of the inventories. With the further popularization of the sensor networks, this proposed system may be implemented in the places that require larger-scale logistics tracking and management such as warehouse and supply chain to facilitate better information flow across the retail supply chain.

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