Advancing Retail Operations: A Customizable IoT-Based Smart Inventory System

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Abstracts: The retail sector has encountered formidable challenges in recent years, particularly concerning food sustainability and the need for reduced manpower, which have been further exacerbated by the COVID-19 pandemic. The inventory management process involves critical tasks such as environment checking, product inspection, and stock arrangement, all of which are essential for maintaining product quality. Price label management is another crucial aspect of retail operations, providing key information to potential customers. However, the labor-intensive process of installing and replacing price labels, as well as adapting to market trends, poses efficiency and sustainability concerns. To address the aforementioned challenges, we have proposed an IoT-based inventory management system that consists of three interconnected components: a smart shelf that keeps real-time track of humidity, temperature, and air index; electronic shelf labeling that allows for easy updating of product information from mobile/PC devices; and RFID-based stock sorting to track product in/out and location. Hence, the proposed integrated solution significantly enhances operational efficiency, reduces overall workload, optimizes inventory management tasks, streamlines operations, and mitigates financial losses associated with inefficient processes.

Keywords: Internet of Things (IoT), Smart Inventory Management (SIM), Retail Operations (RO), Food Sustainability (FS), Smart Shelf (SS), Electronic Shelf labels (ESL), RFID Stock Management (RFID SM).

1. INTRODUCTION

Retail, encompassing the direct selling of merchandise to consumers, plays a vital role in our daily lives and serves as the final stage of the goods distribution chain. The retail industry, faced with challenges of food sustainability and reduced manpower, has witnessed significant advancements driven by the advent of Industrial Revolution 4.0. Intense competition in the global market necessitates the adoption of technologies to optimize operations and maximize profit. Among these technologies, the smart inventory system has emerged as a promising solution for the retail industry. Traditional stock management practices relied on physical media such as ledgers and books to record essential information, including purchase records, sales, customer details, and supplier details. However, these manual processes often prove inefficient, particularly for businesses of larger scales, leading to difficulties in tracking specific records and compromising overall performance due to documentation limitations (Perera, 2013).

To address these challenges, Indoor Radio Frequency Identification Detection (RFID) stock management systems have been introduced for tracking and database record purposes. By registering every product into a database server upon its arrival at the warehouse, RFID systems enable efficient tracking of good's status and provide a reliable accounting document. This automation significantly reduces the need for manual stock checking, minimizing human errors, and replacing paperwork with the use of RFID readers to refresh the status (Vidhya, 2016; Khanna, 2016). Additionally, RFID tags can store specific information such as purchase time and customer contact, facilitating easy retrieval when needed. Monitoring the condition of goods is crucial for effective inventory maintenance. However, manual processes involving visual checks by multiple personnel can be slow and prone to human error, often taking several days to complete. Identifying defective items becomes challenging within such processes (Perera, 2013). To overcome these limitations, IoT-based smart shelf monitoring systems are introduced, incorporating various sensors to collect diverse information for evaluation and analysis of goods' status. For instance, temperature and humidity sensors enable continuous monitoring of the warehouse environment by collecting data and plotting it on graphs. Abnormal situations trigger notifications to workers, enabling prompt identification and resolution of issues. Moreover, smart shelf systems offer customization options, allowing for the addition of modules and sensors to enhance system reliability. (Rashid, 2014) proposed a smart shelf system that utilizes RFID technology to simplify the stock monitoring process and increase accuracy.

Pricing plays a crucial role in marketing strategies as consumers consider it a vital criterion before making a purchase. Promotions, aimed at attracting customers, often require manual labor and incur significant costs due to the replacement of previous price tags. To address these challenges, Electronic Shelf Labels (ESL) offer a wireless and cost-effective solution. ESL enables the dynamic updating of product prices without the need for manual label replacement, effectively controlling labor and material costs (Chen, 2010; Khanna, 2016). This study aims to design and implement a customizable IoT-based smart inventory system. The proposed system comprises three components: indoor RFID management for tracking inventory records and maintaining a comprehensive database, an IoT-based smart shelf monitoring system to monitor inventory conditions in real-time, and an electronic shelf labels (ESL) system to enable dynamic labeling.

2. LITERATURE REVIEW

The implementation of IoT technology has greatly impacted various industries, including the retail sector, in the era of Industry 4.0. Different industrial revolutions have influenced the retail industry's evolution, from steam engines and push-based retail in Industry 1.0 to automation and increased variety in Industry 2.0, and computerization and digital advancements in Industry 3.0. Industry 4.0 has introduced concepts like IoT, virtual reality, cyber-physical systems, and cognitive computing (Perera, 2013; Vidhya, 2016).

These innovations have led to the adoption of technologies such as robots, beacons, and smart shelves in the retail industry to enhance the shopping experience (Liu, 2006). This literature review analyzes and discusses the definition, principles, and applications of these technologies, drawing insights from research and academic sources.

The paper by (Wang, 2015) presents a study on designing an asset management system using IoT technology. The system architecture comprises four layers: device, data, communication, and application layers. The device layer consists of a computer as the central processing unit for generating asset identification and transmitting signals to the database in the data layer. Additionally, a handheld device facilitates wireless data synchronization with the application layer. Asset information is stored using barcode generators and RFID card dispensers for label or tag production during asset registration. The data layer employs both SQL server and SQLite database, with SQL server serving as the central server and SQLite establishing a connection between embedded devices and the central server. Wireless communication technologies such as Wi-Fi and GPS enable data transmission between devices and the database server. The collected data is stored in the database server, allowing users to track assets effectively. However, the IoT-based asset management system and RFID-enabled warehouse management faces potential limitations. These may include concerns regarding privacy and security (Kalange, 2017).

In their study, (Lee, 2017) proposed the focus on the implementation of an IoT-based data transmitting system in a smart warehouse using Ultra-Wideband (UWB) and RFID technology. The objective is to enhance operational efficiency and real-time data integration within the warehouse management system. The researcher proposed the integration of RFID technology into forklifts. The forklifts are equipped with RFID module units and data processing units. The system incorporates two antennas and readers, positioned strategically on the forklift. The first antenna is placed at the front of the fork head to detect RFID tags on digital pallets, while the second antenna is positioned at the bottom of the forklift to detect the dispatch area of pallets.

The collected data from the RFID system transmitted to server over WLAN enables real-time data integration and provides accurate information about the location and status of goods within the warehouse. The integration of UWB and RFID technology in forklifts enables automated data collection, eliminating the need for manual input and ensuring real-time data synchronization. However, the study does not delve into specific implementation details or provide comprehensive evaluation results. Further research and practical experiments are needed to validate the effectiveness and scalability of this proposed system in real-world smart warehouse environments.

(Rezwan, 2018) developed a smart kitchen inventory (SKI) system for monitoring and managing inventory items. The system utilizes sensors and internet connectivity to remotely monitor storage and transfer real- time data to a database. Users can access the system through web pages or mobile apps to check the inventory status and receive low-stock notifications. The system employs load cells for measuring countable products and a combination of Light Dependent Resistor (LDR) and Light Emitting Diode (LED) for detecting uncountable products. Wireless communication is facilitated through the ESP8266 module. The SKI system successfully achieves its goal of monitoring inventory and providing a user-friendly interface for order management. However, SKI system relies on stable internet connectivity for real-time monitoring. Any disruptions in the internet connection can hinder the accuracy and timeliness of the inventory data. Additionally, the reliance on sensors for detecting product quantities may introduce inaccuracies if the sensors malfunction or encounter calibration issues.

The research conducted by (Miguez, 2019) focuses on the implementation of a system using 2.7-inch E-ink display modules and the LoRa transceiver module SX1278 for wireless communication. The control of these modules is managed by the PIC18F47K40 microcontroller. The selection of PIC18F47K40 is based on its support for deep sleep mode and its 128Kb flash memory, which allows for storing images for display purposes. The device is powered by a $LiMnO_2$ battery with a capacity of 500mAh. To minimize power consumption, the device remains in deep sleep mode while operating and periodically checks for update requests from the server. When new updates are available, the device wakes up from deep sleep mode to retrieve messages from the server.

(Shukla, 2019) proposed an IoT-based smart fruit warehouse monitoring system. It aims to centralize monitoring and automate warehousing, tracking temperature, humidity, and light intensity. Users access data and control parameters through a website or app. Three core functionalities include sensor data collection, cloud-based data visualization, and wireless communication. A Raspberry Pi serves as the central processor, while DHT11 and GY30 sensors monitor inventory conditions. The system features automatic alerts for abnormal conditions, enhancing fruit quality control. Android Studio and Python with Django are used for mobile and web app development, with Thingspeak for data visualization. The system successfully met its goals, enabling remote monitoring and control for optimized fruit warehousing. However, this IoT-based fruit warehouse monitoring system may have limitations related to real-time responsiveness and scalability in larger warehouse environments.

(Rajesh Bose, 2022) and his colleagues have presented a forward-thinking approach to enhance inventory management, primarily tailored for the construction sector, with a specific focus on Indian construction companies. By integrating barcode technology with modern advancements such as Cloud Computing, Arduino-based wireless station nodes, and IoT integration via a secure web portal, they offer a promising solution to streamline inventory control and operational efficiency. However, the initial implementation costs and the requirement for specialized training could present challenges. Additionally, ensuring data security and compliance with regulations in a cloud-based system is critical. While the study suggests broader applicability, customizing and adapting this approach to diverse industries and regions may involve additional complexities and considerations.

In healthcare, (Krishnakumar's, 2022) research underscores the vital role of efficient inventory management in delivering cost-effective, high-quality patient care. Despite the potential of Medistock inventory systems for optimization, challenges such as data accuracy, training gaps, and standardization persist. This review explores current trends in Medistock inventory management, highlighting its significance in healthcare operations. It discusses techniques like RFID technology, neural networks, and just-in-time systems for enhanced control. The study also examines challenges and offers potential solutions, emphasizing the need for tailored inventory systems to reduce costs and improve patient care. Krishnakumar's work ultimately stresses the importance of strategic inventory management in healthcare settings

Table 1: Summary of related work

Author	Features	Advantages	Disadvantages
(Lee, 2017)	-RFID-enhanced forklift -Product Identification	-Mass transportation -Simplify the operation tasks	-Large Space required -High skill technician needed -High Initial Cost
(Wang, 2015)	-Asset Management -Handset System -Product Identification -Web Interface	-Able to real-time monitor the asset -Able to review the record -User Friendly	-High initial cost required -Higher level of difficulty
Rezwan, 2018)	-Stock Checking -Web GUI -Weight Checking -Wireless Communication	-Low-Cost Solution	-Low Accuracy for object detection
(Miguez, 2019)	-PIC18F47K40 based -WiFi-Communication	-Able switch to deep sleep mode	-External WiFi module required -Only allow short distance communication
(Shukla, 2019)	-Temperature Light Intensity and Humidity Identification - Mobile Application Feedback Mechanism - Dashboard Visualisation	- Able to notify user for specific condition - User able to perform action through remote access inventory - Able to generate chart regarding sensor data	- High development time required

3. Methodology:

The proposed Smart Inventory Management aims to revolutionize the retail industry by simplifying operations and enhancing efficiency. The system comprises three modules, i.e., Indoor RFID Management Systems: The objective of this module is to monitor the inventory of the retail store to reduce the workload of workers and increase efficiency of stock management. Smart Shelf Systems: The main target of this module is to help the retailers to prolong the on-shelf time of products and make decisions accordingly when the item is close to expiry date or outdating, and lastly, Electronic Shelf Labels System: The aim of this module is to replace the traditional price tag in the store in order to automate some operating tasks and reduce time consumption on installation of the price tags.

3.1. System Architecture:

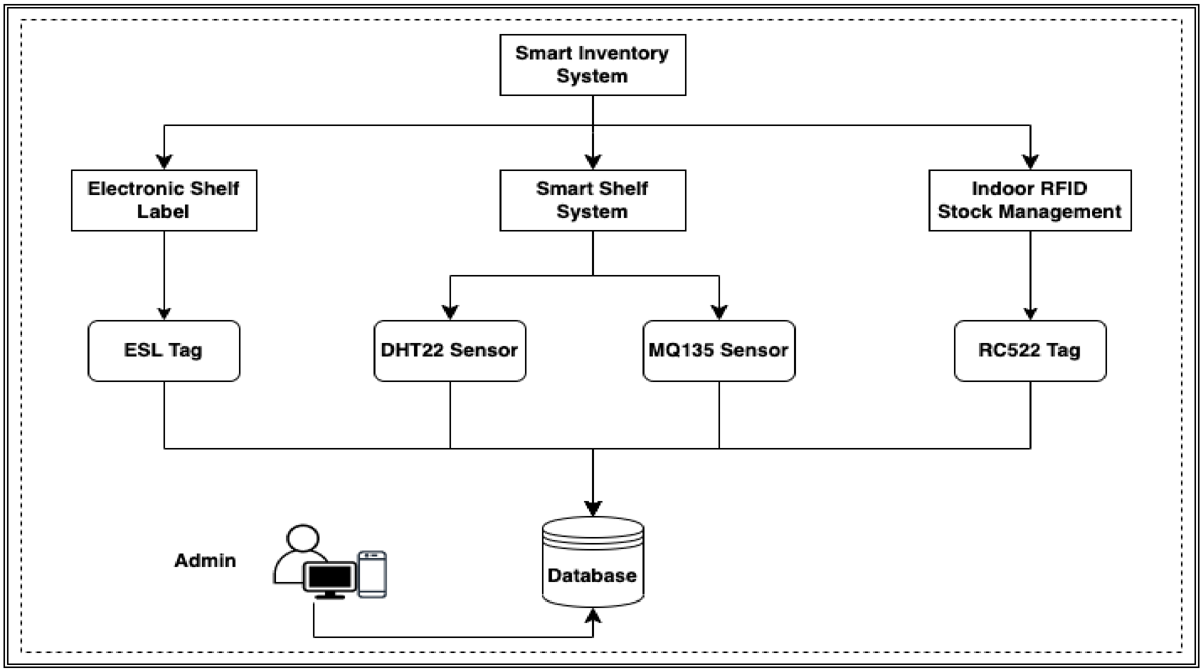

Figure1: System Architecture of the Smart Inventory System

3.1.1. Flow Diagrams:

In this section, we present flow diagrams for the three modules incorporated in the inventory managementsystem: RFID stock management depicted in Figure 2, ESL (Electronic Shelf Label) depicted in Figure 3 and Smart Shelf shown in Figure 4. These flow diagrams provide a visual representation of the sequence of actions and interactions within each module, outlining the key processes involved in the inventory management system.

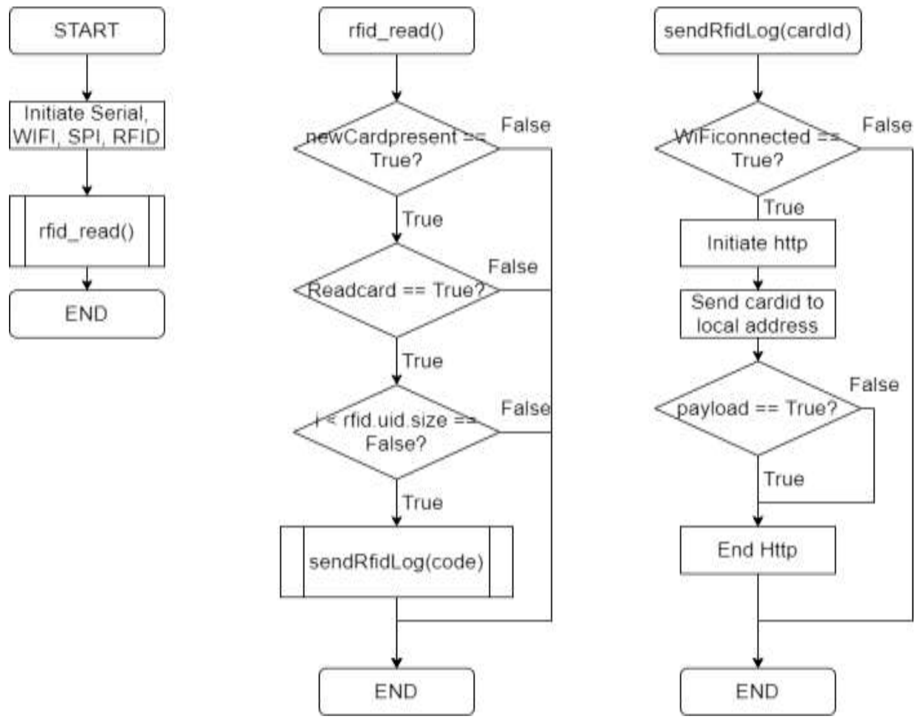

Figure 2: Program flowchart of Indoor RFID Management

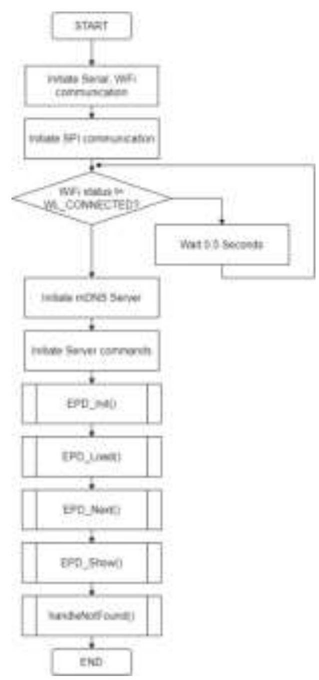

Figure 3: Program flowchart of Electronic Shelf Label

Figure 4: Program flowchart of dht_22 and mq135 function for Smart Shelf

3.2. Implementation

The implementation of the proposed smart inventory management system involves the practical executionand deployment of the system architecture described earlier. This section provides an overview of the implementation process, including the steps taken to bring the system to life and make it operational.

3.2.1. Hardware Requirement

- ESP32 Board
- Raspberry Pi Board
- E-Ink- Display
- Universal E-Paper ESP32 Raw Panel Driver Board
- RFID Module: RC522
- DHT22
- MQ135
- DC Battery

3.2.2. Software Requirments

- Arduino Integrated Development Environment (IDE)
- Node-Red
- Fritzing
- Telegram
- Solid works
- MySQL (PHP, Server)
- Ultimaker CURA
- Adobe Illustrator

The implementation of the system involves the utilization of various components to enable seamless data collection, tracking, and inventory management. Initially, the RC522 RFID module, used for contactless card communication as depicted in Figure 5, ESL tags for product labeling and identification shown in Figure 6, MQ135 air quality sensor for detecting harmful gases, and DHT22 sensor for temperature and humidity monitoring as shown in Figure 7, are connected to microcontrollers, which are then linked to a Raspberry Pi serving as the central processing unit. Additionally, a 2.9-inch E-Ink display panel is also connected for visual output, powered by a 5V battery. The subsequent steps involve software setup, encompassing the use of various software tools and platforms to support system functionality and communication. This includes the utilization of the Arduino IDE for programming and uploading code to the microcontroller boards, Raspberry Pi-based Node-RED for flow-based programming and IoT integration, Fritzing for designing the virtual circuit of the prototype, Telegram for automation and information dissemination, Solidworks for the design and modeling of the mechanical system, MySQL as the web database, Ultimaker Cura for generating G-code files for 3D printing, and finally, Adobe Illustrator for creating price tag images for the electronic shelf labels system.

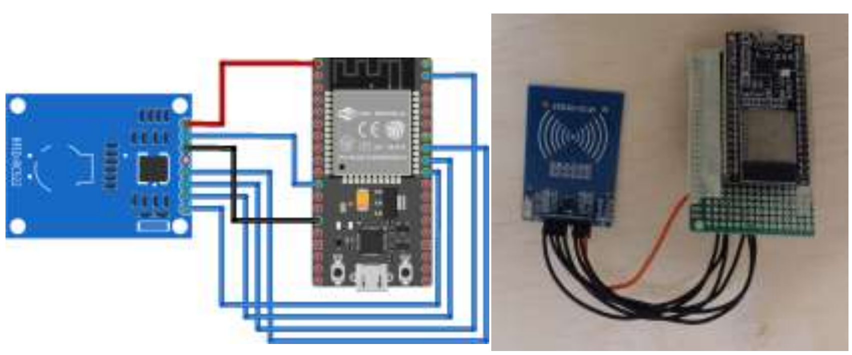

Figure 5: Circuit Drawing and Real Circuit of Indoor RFID Inventory RFID System

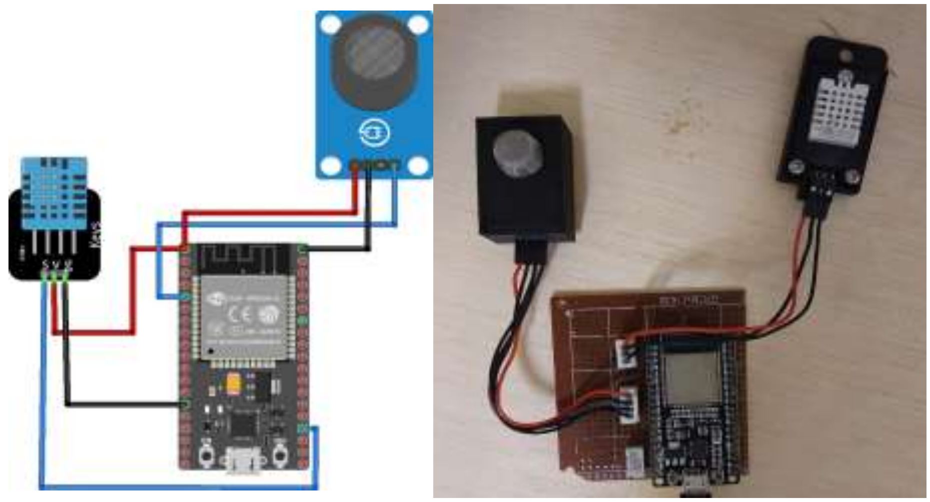

Figure 6: Circuit Drawing and Real Circuit of Smart Shelf System

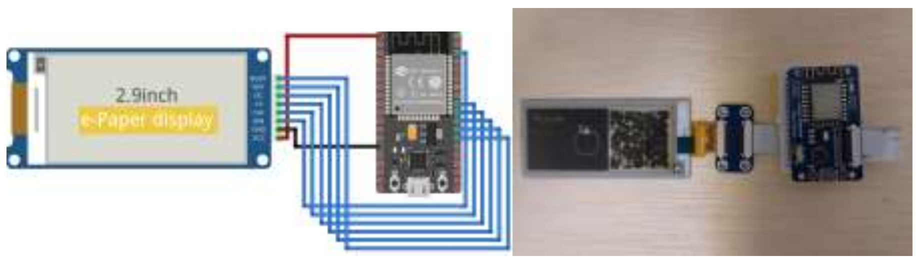

Figure 7: Circuit Drawing and Real Circuit of Electronic Shelf Label System

By employing the aforementioned hardware and software tools, the smart inventory management system was able to efficiently collect and manage inventory data, monitor environmental conditions, and provide real-time updates through integrated display panels. The implementation process involves carefully integrating and configuring these components to ensure smooth communication and seamless functionality among them. Figure 1 illustrates the implemented smart inventory management system, highlighting the three modules: RFID management system, smart shelf system, and electronic shelf labels system.

4. ALGORITHM

The algorithm for the system design includes several functions that perform specific tasks and control the flow of information explained below:

Table 2: Overview of code for design Algorithm

No	Function	Functionality
1	Start ()	It marks the start of the entire system
2	Controller()	Orchestrates the flow of information and controls the working of the entiresystem.
3	Product_Info()	Stores and manages information about a specific product.
4	Reader ()	Reads the product information storedin the RFID tags and environment data.

5	Alert_Warning ()	Generates alert when the environment data (temperature etc)reach specified threshold.
6	End ()	Marks the end of the system operation and ensures proper termination of processes.

Step 1: Start()

Step 2: Controller()

Step 3: Product_Info()

Step 4: Web_ Application()

Step 5: Start() → Web_ Application ()

Step 6: Mobile_ Application() → Controller ()

Step 7: Controller() → Web_ Application()

Step 8: Tag() → Web_ Application()

Step 9: Web_ Application() → Reader()

Step 10: Reader() → Controller()

Step 11: Controller () → Reader()

Step 12: Reader() → { Tag(), Alert_warning() }

Step 13: Alert_Warning() → Product_Info(), Env_Temp(), Env_Humi(), Env_AirInd()

Step 14: Controller () → Product_Info()

Step 15: Controller () → Stock_Mgmt()

Step 16: Stock_Mgmt() → Stock_inOut(), stock_location()

Step 17: End()

These steps outline the sequence of functions and interactions within the system, ensuring the proper handling of product information, reading RFID tags, generating alerts, managing stock, and eventually marking the end of the system operation.

5. RESULTS AND ANALYSIS

The results and analysis of the implemented system demonstrate its effectiveness in improving inventory management. The RFID RC522 module successfully scanned RFID tags and collected accurate data on product stock and location. Accessing the information through the local server's GUI site allowed for easy management, and manual editing of the backend database provided flexibility. Communication between the ESL tag and mobile/PC devices was seamless, whether wirelessly or through the OTA technique. This facilitated convenient updates and modifications of product information on the go, enabling users to upload labels from their mobile devices or computers. Thorough testing of the Smart Shelf module and utilizing the Node-Red dashboard provided comprehensive insights into the environment. The DHT22 sensor effectively captured temperature and humidity data, while the MQ135 sensor accurately measured the air index.

Table 3: Recorded data from RFID Tag

Log ID	Status	Card ID	Log Date
1	Rack-2	1607610	April-14, 2022, 10:53 pm
2	Rack-3	2343580	April-14, 2022, 10:54 pm
3	Rack-2	2239020	April-14, 2022, 10:54 pm
4	Checkout	2343580	April 14, 2022, 10:54 pm
5	Rack-2	693310	April 14, 2022, 10:54 pm

Table 4: Recorded data from Electric Shelf Label (E-Ink display)

No	Product Name	Product Price	Updated Product Price
1	Apple	RM 1	RM 2.10
2	Avocado	RM 3	RM 2.70
3	Grapes	RM 5	RM 7

Table 5: Recorded data from smart shelf (environment)

No	**Sensor Tag**	**Temperature**	**Humidity**	**Air-Index**
1	MQ135	-	-	2942
-	-	-	-	2774
-	-	-	-	2825
2	DHT22	27.7	43.8	-
	-	30.3	45	-
	-	33	48.3	-

Multiple tests were conducted in various scenarios to evaluate the overall functionality of the system, which consists of three modules. The data obtained from RFID stock management are presented in Table 3, showcasing the acceptance and placement of two items, Card ID 167810 and 2343580, in the warehouse. The initial status indicates that these items were located on Rack 2 and 3, respectively. Subsequently, a stock-out operation was performed, and real-time updates were observed for the status of Rack item ID 2343580, reflecting its checkout. The data acquired from the Electronic Shelf Labels (ESL) revealed the initial placement of three products, namely Apple, Orange, and Avocado, along with their corresponding pricing set at RM 1, RM 3, and RM 5, respectively. Subsequently, a product labeling update was performed using a PC or mobile device, resulting in successful price updates on the ESL tags associated with each individual product. Specifically, the ESL tags for Apple, Orange, and Avocado were updated with new prices of RM 2.10, RM 2.70, and RM 7, respectively, presented in Table 4.

Finally, the smart shelf system incorporated MQ135 and DHT22 sensors to gather crucial environmental data, including air quality index, temperature, and humidity. The obtained air quality indexvalues from the sensors were 2942, 2774, and 2825, respectively. Simultaneously, temperature and humidity measurements were recorded. The temperature readings were 27.7°C, 30.3°C, and 33°C, while the corresponding humidity values were 43.8%, 45%, and 48.3% presented in Table 4. These data points offer valuable insights into the monitored environmental conditions by the smart shelf system, enabling effective management and control of the storage environment.

The collected data was presented in graphical displays, enhancing monitoring and tracking capabilities. Overall, the implementation of this system resulted in significant time and effort savings. Its user-friendly interface and easy accessibility further contributed to its practicality. The feasibility of this system for inventory management is evident, establishing its value as an efficient solution for businesses.

6. DISCUSSION

The system underwent rigorous testing across a range of conditions, enabling a comprehensive evaluation and validation of its capabilities. The extensive testing process confirmed the system's successful functionality and performance, establishing its feasibility for inventory management purposes. By integrating reliable data collection methods, efficient communication protocols, and intuitive graphical visualization, the system presents a holistic solution. The positive outcomes observed during the implementation further reinforce the system's potential to enhance inventory management processes across diverse business contexts. The combination of these factors underscores the system's value and the promising prospects it holds for optimizing inventory management practices.

CONCLUSION

This paper introduces a customizable IoT-based smart inventory system for the retail industry. Traditional inventory management practices have proven to be inefficient and come with several limitations (Kalange, 2017). Therefore, there is a need to shift towards advanced technologies to optimize operations and maximize profitability. The implementation of RFID technology enables efficient tracking and database recording, reducing the need for manual stock checking and minimizing errors. The IoT-based smart shelf monitoring system offers real-time monitoring of inventory conditions, facilitating prompt issue identification and resolution. Electronic Shelf Labels (ESL) provide a wireless and cost-effective solution for dynamic pricing, improving marketing strategies and cost control. Smart Inventory offers several benefits to retailers, including enhanced operational efficiency, reduced human errors, and improved customer satisfaction.

Looking ahead, future research and development efforts can focus on further optimizing the system's performance and exploring additional features tailored to meet specific industry requirements. Continuous improvement and expansion of the system's capabilities will contribute to enhanced inventory management practices, leading to increased efficiency, productivity, and reduced implementation costs for businesses.

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