ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VI, June 2025

Smart Shelf System for Automated Stores

Chintan Jethva, Shantanu Nilesh Deshmukh, Kaustubh Vijay Pawar, Tanmayee Vinayak Bochare

Vivekanand Education Society's Institute of Technology Mumbai, India

DOI: https://doi.org/10.51583/IJLTEMAS.2025.1406000107

Abstract: The tracking and managing of the on-shelf products and stock in an automated store is performed manually in regular periods of time. So, more resources are required, which increases the nances. Automated stores are also plagued by the major issue of shoplifting. The proposed smart shelf system solves these issues. Each shelf is equipped with load cells and RFID modules integrated with stm32 bluepill to monitor shelves in real-time. Communicating via Ether- net, they connect to a central Raspberry Pi unit, facilitating man- agerial oversight. This innovation tackles ine ciencies of manual tracking and security vulnerabilities, o ering automated solutions. By streamlining operations and enhancing stock prediction, these systems optimize customer experience while mitigating shoplift- ing risks. This integration of technology rede nes retail, providing adaptive solutions to meet contemporary market demands.

I. Introduction

Supermarkets face a myriad of challenges in management, ranging from inventory control to customer satisfaction. One signi cant issue is inventory management. Keeping track of thousands of products across various categories, managing expiration dates, and ensuring adequate stock levels can be complex and labor-intensive. Inaccurate inventory management can lead to stockouts, overstock- ing, and increased costs due to spoilage or wastage.

Another pressing concern is optimizing the layout and design of the store to enhance the shopping experience and maximize sales. Deciding on product placement, aisle arrangements, and signage requires careful planning to encourage customer navigation and impulse purchases. Additionally, managing shelf space e ectively is crucial for promoting products and accommodating seasonal variations in demand.

Supermarkets also grapple with the rising threat of theft and security breaches. Shoplifting, employee theft, and organized retail crime contribute to signi cant nancial losses each year. Imple- menting robust security measures, such as surveillance cameras, security tags, and anti-theft systems, is essential to deter theft and protect both merchandise and customers.

Furthermore, supermarkets must adapt to changing consumer preferences and market trends. The rise of online shopping, demand for healthier food options, and increasing emphasis on sustainability require supermarkets to innovate and diversify their o erings to stay competitive.

Overall, e ective management in supermarkets requires address- ing these multifaceted challenges by leveraging technology, imple- menting best practices, and prioritizing customer satisfaction and operational eciency.

This research aims to implement a system where the manage- ment can easily navigate the challenges of optimizing inventory management and eliminate the threat of theft and security breaches and have a system that can adapt to changing customer preferences.

II. Literature Survey

The systems implemented to manage supermarkets currently are very labor-intensive and further increase costs for the management as well as the user. The IoT involves a massive network infrastruc- ture that uses communication capabilities and data capture to link physical and virtual objects[1]. This IoT technology is commonly implemented with Wi , Zigbee, LORA, Bluetooth, Mqtt protocols. The IoT technology implemented with Zigbee was studied in the article [1] wherein an RFID system was implemented to solve the consumer identi cation and recognition of commodities.

The major setback that the system in [1] faced was implementing the backbone of the system with ZigBee which is susceptible to hacking due to its unreliable and weak encryption methodologies and limited security features. The system proposed in [1] also didn't provide any solution from the point of view of the manager for inventory management. Drawbacks in [1] were issued in [2] where a system was developed with IoT and arti cial intelligence where the shelves have cameras where the stock-keeping units are identi-ed through an image taken from a camera, which uses raw inner container images sized 300x300 and then locates bounding-box of goods. Goods are detected based on color features, mathemat- ical morphology, texture, and depth features through single-shot detector algorithm [2].

The article [2] gave a solution in one aspect in the management perspective of the store and also provided functionality for easy billing of items but the single shot detector algorithm is hard to train and has accuracy issues while detecting small and overlapped objects. Also, the single shot detector algorithm is implemented on a cloud rather than locally which increases the delay in the processing and increases the cost due to the introduction of an external service of the cloud.

Building upon the ndings in [2], the study in [3] designed an au- tonomous tracking shopping cart to assist consumers in shopping. This system has the characteristics of automatically identifying commodities, loading commodities, and following consumers

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VI, June 2025

inde- pendently. It enhances users' sense of autonomy and also designs a member login system to optimize the warehousing of unmanned supermarkets while providing personalized discount promotions for users[3]. However, the smart cart proposed is not equipped with any security measures to prevent shoplifting. The cart does not provide any bene ts to the store management. The cart can load and identify the commodities but the YOLOv4 network has been used which is di cult to train and also struggles with small and overlapping object detection.

The studies [1–3] talk everything about the user experience and nothing signi cant from the management perspective. Hence a need for a management-oriented solution that would help keep track of stock on each shelf was identi ed. Each shelf was to be treated as a node and to identify the number of units present. To study this requirement articles [4] and [5] were referred to understand the working of a load cell and its application as a weighing scale which can eventually provide the number of items on the shelf.

Article [6] implemented a security system with the help of a servo motor or solenoid lock and RFID where the servo motor or solenoid lock would open with the identi cation of the RFID tag and would give access to the authorized user. Studying [6] a need for study on di erent types of servo motors arose which was satis ed by article [7].

As discussed in [1], ZigBee technology posed signi cant security challenges, a concern also echoed in the subsequent study by [2] so a study of a secure system was achieved from [8] where the ethernet protocol was used to communicate with systems with axed frame format and better encryption capabilities having point to point communication between server and node.

The articles [9], [10] and [8] commonly used Raspberry Pi as the central server with ethernet or WiFi as a backbone. Inferring information from [8] the technology of ethernet communication mainly depended on internet protocol addresses and their respective ports where data communication takes place which is collectively called socket-to-socket communication.

The TCP/IP protocol is more secure than the UDP protocol [11]. But inferring from [11] and [12] where [11] implemented TCP/IP and [12] implemented UDP, it was inferred from the articles that the TCP/IP communication used more resources in the microcontroller due to the requirement of constant need of making and breaking connections for communicating between two nodes and constant connection in [11] may result in bu er over ow in the microcon- troller. But in the case of [12] UDP needs to connect only once and the information could arrive or transmit anytime with negligible possibility of crash of the microcontroller used. However, the draw- back is that it is not as secure as the TCP/IP protocol packets that are transmitted. There is a possibility of UDP packet spamming which could overwhelm the server and cause it to crash [13]. Hence in [14] pros and cons of a local area network were studied.

Hence the studies [1],[2],[3] pose a signi cant research gap and need for the implementation of practical systems concerning the management and security systems for supermarkets which could increase the e ciency and security of such enterprises.

Proposed System

The proposed system aims to implement a solution that will have features for the management of the system as well as automate the billing process for the customers. The proposed system is divided into three main sections:

- Sensor Node
- Router or Switch
- Central Server

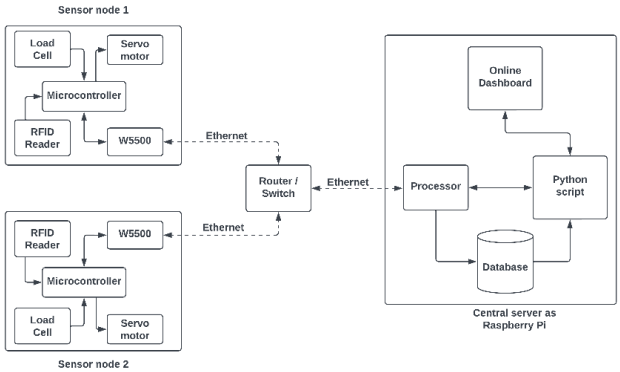


Figure 1: Block Diagram

The block diagram, illustrated in Figure 1 delineates the archi- tecture of a novel system engineered to streamline supermarket management processes. It is comprised of 3 pivotal sections.

Sensor Node or Sensor units The sensor node is the root- level block of the system whose role is to capture data on the shelf and transmit it to the central server. This unit integrates a load cell, an RFID reader, and a servo motor at its core. The

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VI, June 2025

sensor node is implemented with STM32FF103C8T6 as the microcontroller with an ethernet interface. This unit harvests the raw data from the load cell which gives the weight of the items present on the load cell and calculates the number of items kept on the load cell. Further, this processed data is transmitted to the central unit through the router for updation. This unit also implements a security feature that will only give access to the authorized user with the help of the RFID reader which when detects a tag opens the shelf for the user only if the tag is veri ed from the central server.

Router and switches This section serves as the backbone of the system which implements a star topology, responsi- ble for routing and directing the processed data streams to their designated destinations. This block comprises robust networking infrastructure, including routers, switches, and data transmission protocols, engineered to facilitate seam- less communication and data ow across the entire system architecture. Each unit in the system is assigned its perma- nent IP address for their MAC addresses. This increases the security of the system as no other devices other than the list of authorized devices are allowed into the network.

Leveraging high-speed data networks and intelligent rout- ing algorithms, this unit orchestrates the e cient transfer of data packets between the sensor node's data processing unit and the central server. By ensuring reliable and timely data transmission, this block plays a pivotal role in main- taining system responsiveness and integrity, even amidst uctuating data loads and network conditions.

Central Server Positioned as the nerve center of the system, the central server encompasses the central server and user interface components essential for data storage, manage- ment, and user interaction. At its core, the central server serves as a repository for aggregated data streams originat- ing from the sensor unit. Concurrently, the central server hosts a user-friendly dashboard interface tailored to the needs of store managers and stakeholders. Through this intuitive interface, managers gain comprehensive visibility into inventory status and other metrics. The user interface empowers managers to make informed decisions, optimize resource allocation, and respond proactively to emerging business trends and customer demands.

Together, these interconnected blocks constitute a robust system architecture designed to revolutionize supermarket management practices. By harnessing the power of data-driven insights, seamless data routing, and intuitive user interfaces, the proposed solution aims to enhance operational e ciency, optimize resource utilization, and elevate the overall shopping experience for customers.

Implementation

In order to validate the design and functionality the system shown in Figure 1 was implemented. The system was implemented with the backbone as ethernet, the sensor node was implemented with an STM32FF103C8T6 microcontroller and programmed in embedded C, and the central server including the dashboard was implemented in python.

As shown in Figure 2 the sensor node was implemented with the load cell which measures the weight of the items placed on it with a safety feature of locking and unlocking mechanism with the help of a stepper motor.

The dashboard of the system implemented in python is shown in Figure 3 and Figure 4. The dashboard of the system runs on the central server where the python scripts exchange critical information over the ethernet interface.

The ow for the system is explained in Figure 5. The process for the system is as follows:

- The customer enters the shopping complex and is given a RFID tag which is linked to his account.
- The customer according to his needs scans the RFID tag on the shelf that he wants to buy items from.
- The inbuilt RFID tag reader detects the card and asks the central server for its authenticity.
- If the tag is authentic then the shelf door opens for the user.
- The shelf door once opened stays open for a while. The user can take out the required items in the window of time for which the shelf is open.
- The shelf door closes and the system updates the dashboard in the central server for the manager.



Figure 2: Sensor Node

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VI, June 2025

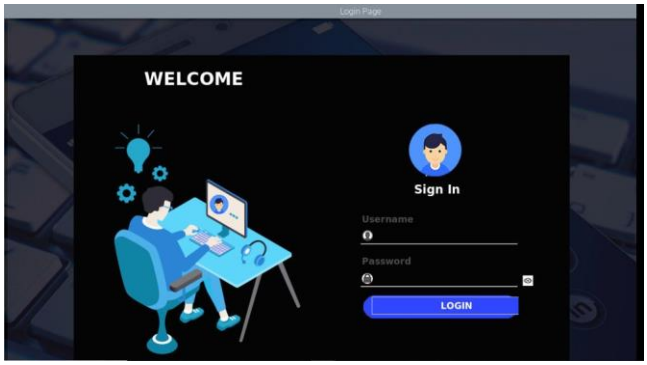


Figure 3: Login Page for Manger

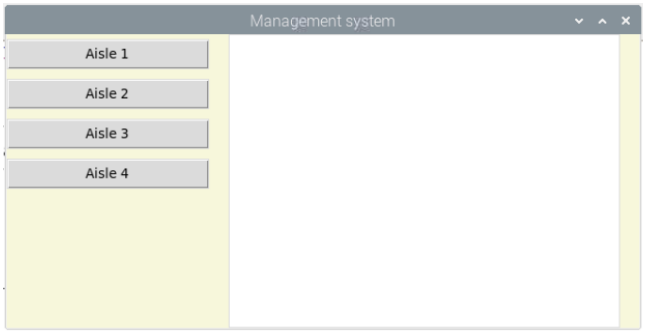


Figure 4: Dashboard for Manager

Additionally, the sensor node periodically updates the in- formation about the shelves to the server.

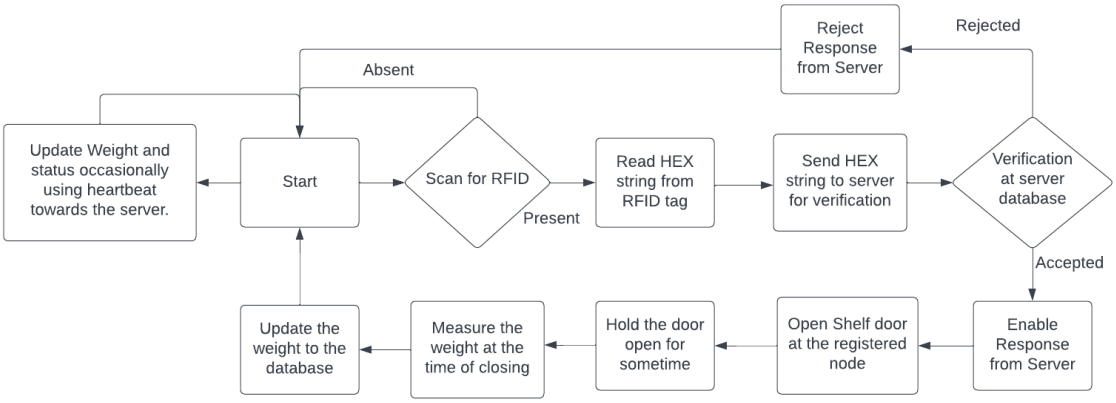


Figure 5: Flow Diagram

III. Results

Initially, packet transfer was implemented to check the data trans- mission between the sensor node and the central server and vice versa. Figure 6 shows the items on the shelf of aisles after the updation of the items.

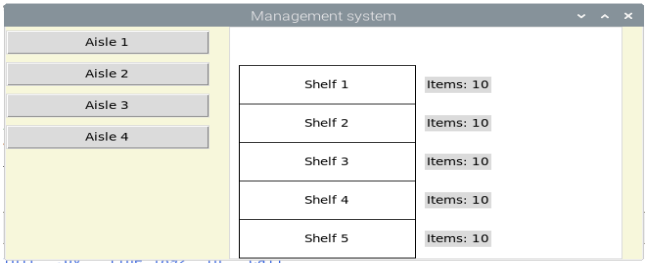


Figure 6: Dashboard after updation

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VI, June 2025

Further, the dashboard on the central server and sensor node was connected and the data was updated for the manager on the dashboard for each aisle. For the manager, the dashboard could only be accessed after validating the login details of the user.

Using commands from the server side the data was able to be transmitted to the sensor node and the data was transferred back to the central server with the help of UDP port communication.

The sensor nodes were able to detect the RFID tags and verify them with the database on the central server and receive command signals from the central server to open up the compartment. For an experiment, multiple whiteboard markers were placed on the sensor node as shown in Figure 2. The tags were veri ed in the server and logged on to a log le on the Raspberry Pi for security purposes and as the required items were removed from the sensor node the number remaining items were transmitted to the central server for updation and also logged into the log le.

IV. Conclusion and Future Scope

In this study, we have presented a comprehensive investigation into the development and implementation of a novel system aimed at enhancing supermarket management e ciency. Our proposed system o ers a transformative approach to traditional supermarket operations, enabling data-driven decision-making, and real-time monitoring.

Through the integration of sensory devices and network in- frastructure coupled with software that encapsulates the data and displays it for the manager in a visual form. The objective of the next idea that has been proposed is to im- plement a mobile application for customers where the items that are taken o the shelves by the customer, will be re ected in the shopping cart of the app and the user can pay the amount on the go for the items that the customer purchased. Also, an arti cial in- telligence model can be implemented to predict the store's required restocking of commodities.

A question will arise in a person's mind as to how the customer would return or take o the item that he doesn't need if he/she changes their mind. So a counter speci cally for this purpose would be set up where the customer would submit their RFID tag, take o the items that are not needed o their shopping cart and return the items. And further, pay for the items that the customer has taken. In conclusion, the future scope of our research extends beyond the con nes of this study, o ering a roadmap for continued inno- vation, collaboration, and advancement in the eld of supermarket management. By embracing emerging technologies, sustainability initiatives, and user-centric design principles, our system can evolve to meet the evolving needs and expectations of the modern retail landscape, driving continued value and impact for stakeholders and society at large.

References

1. S. Mekruksavanich, "Supermarket shopping system using r d as the iot applica- tion," in 2020 Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunications Engineering (ECTI DAMT NCON), pp. 83–86, 2020.
2. J. Xu, Z. Hu, Z. Zou, J. Zou, X. Hu, L. Liu, and L. Zheng, "Design of smart unsta ed retail shop based on iot and arti cial intelligence," IEEE Access, vol. 8, pp. 147728–147737, 2020.
3. L. Yao, T. Li, R. Tong, K. Wang, and L. Zhang, "Radar self-following shopping cart based on multi-sensor fusion," IEEE Access, vol. 11, pp. 77055–77072, 2023.
4. V. Kamble, V. shinde, J. Kittur, R. Scholar, and Profesoor, "Overview of load cells," 10 2021.
5. O. Ogunbiyi, Electrical and Computer Engineering Department, Kwara State University, Malete, Kwara State, O. C. Mohammed, L. M. Adesina, Electrical and Computer Engineering Department, Kwara State University, Malete, Kwara State, and Electrical and Computer Engineering Department, Kwara State University, Malete, Kwara State, "Development of an automated estimating electronic weigh- ing scale," ABUAD Journal of Engineering Research and Development (AJERD), vol. 6, pp. 59–66, June 2023.
6. M. Baballe and M. Bello, "Di erent types of servo motors and their applications," 05 2022.
7. G. V. Ganesh, A. N. Reddy, A. S. S. V. Reddy, and N. Chowdary, "Wireless biometric lock using arduino with the iot," in 2022 2nd International Conference on Arti cial Intelligence and Signal Processing (AISP), pp. 1–6, 2022.
8. A. Yiming and T. Eisaka, "Development of an ethernet protocol for industrial real-time communications," pp. 1122 – 1125 vol.2, 11 2004.
9. T. Savić and M. Radonjić, "One approach to weather station design based on raspberry pi platform," in 2015 23rd Telecommunications Forum Telfor (TELFOR), pp. 623–626, 2015.
10. A. Kolya, D. Mondal, A. Ghosh, and S. Basu, "Direction and speed control of dc motor using raspberry pi and python based gui," vol. 5, pp. 74–87, 03 2021.
11. A. V. Zinkevich, "Esp8266 microcontroller application in wireless synchronization tasks," in 2021 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), pp. 670–674, 2021.
12. D. Minchev and A. Dimitrov, "Home automation system based on esp8266," in 2018 20th International Symposium on Electrical Apparatus and Technologies (SIELA), pp. 1–4, 2018.
13. K. Vanitha, S. V. UMA, and S. Mahidhar, "Distributed denial of service: Attack techniques and mitigation," in 2017 International Conference on Circuits, Controls, and Communications (CCUBE), pp. 226–231, 2017.
14. P. Feng, "Wireless lan security issues and solutions," in 2012 IEEE Symposium on Robotics and Applications (ISRA), pp. 921–924, 2012.