Intelligent Smart Trolley using RFID and ESP32 for Automated Billing and Food Nutrition Display

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***Abstract*—In this paper, an Intelligent Smart Trolley is described that employs ESP32 for automated billing, mobility control, and nutritional information display in new retail environments. The suggested solution combines RFID with an ESP32 microcontroller for real-time product identification and automatic billing without the need for a human to intervene at any point. Each item has a unique RFID label associated with it, and the trolley's reader module recognizes that label. The ESP32 interprets the tag information and updates the billing and nutritional information through a mobile or cloud interface via Wi-Fi, so there is no need for manual barcode scanning or waiting in checkout lines. The trolley has DC motors inside along with an IR/RF based remote control for steering, infrared sensors for detecting obstacles, and a buzzer for alerting purposes when an unauthorized or duplicate item is detected. The system runs on a rechargeable battery and is energy efficient. By utilizing IoT, embedded systems, and machine learning-based nutritional computation, the proposed design not only convenience the user but also come with other advantages like reduction of manpower and intelligent, non-contact retail operations.**

***Index Terms*—ESP32, RFID, Smart Trolley, Automated Billing, IoT, Remote Control, Nutrition Analysis, Machine Learning, Retail Automation, Wireless Communication.**

I. Introduction

Transformation in the retail sector has taken place at the hands of Internet of Things (IoT) and embedded system technologies. The trend of Manual billing that is time-consuming, long queues and checking-out by humans are typical of supermarkets and hypermarkets. These traditional methods result not only in less efficiency but also in higher operational costs and errors that are caused by manual intervention. Smart trolleys have come up as a concept to provide automation along with convenience and smart data handling in the retail sector.

An Intelligent Smart Trolley using ESP32 is the main proposal here, which is meant to automate product billing, movement, and nutrition data processing. The system uses RFID technology for labeling product contactless and making real-time item detection as well as billing. The ESP32 microcontroller is the main processing unit where RFID data acquisition, motor controlling for trolley movement, and Wi-Fi communication for cloud synchronization are integrated. Instead of the traditional display modules, the system is equipped with a mobile or cloud-based dashboard that gives users live billing updates, nutritional breakdowns, and digital payment options. Moreover, the trolley has DC motors and an IR or RF-based remote control installed, which allows the users to move it wirelessly throughout the shopping area. The IR sensors are used by the trolley to avoid obstacles and navigate safely while, in case of unauthorized or duplicate product detections, the buzzer sounds. The power is supplied by a rechargeable battery making the system reliable and portable in its operation. Machine Learning (ML) techniques' incorporation lets the system interpret and present nutritional information in terms of calories, fats, sugar, and protein thus, creating health-conscious shopping.

With this breakthrough, the billing process is not only speeded up but also the customer satisfaction is increased, cashless transactions are made easier, and the need for staff is reduced. The combination of IoT, embedded hardware, and ML analytics is a scalable solution that can be deployed to supermarkets, retail chains, and smart shopping areas. This system is a move towards the establishment of self-operating,

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intelligent retail ecosystems that are in alignment with Industry 4.0 and smart cities.

II. Related Work

studies on smart buying systems, in particular those using RFID and IoT technologies, has won widespread attention in recent years. This phase presents an in depth review of associated research addressing automation in retail, wise billing, and integration of synthetic intelligence for more advantageous purchasing studies.

Kumar and Kaur [1] proposed one of the earliest prototypes of an RFID-primarily based clever trolley designed to automatically read product tags and generate payments without manual checkout. Their gadget proven reduced waiting time however lacked wireless records transfer functionality. in addition, Salim and Sajan [2] provided a microcontroller-based purchasing cart using RFID sensors and an lcd show for real-time billing, enhancing user experience in supermarkets.

Basanagoudra et al. [3] evolved an IoT-enabled RFID billing trolley that communicated wirelessly with a important server, disposing of the want for manual cashier operations. Their implementation highlighted the efficiency of mixing ESP modules with RFID scanners. Balamurugan and Nagarajan [4] brought a comparable idea named "smart Shoppe Trolley," specializing in reducing human interaction and selling automated billing through radio frequency technology.

in addition refinement became made by Bodravara et al. [5], who designed a low-price computerized billing device integrating RFID with Arduino and GSM modules. Their work stronger the portability and reliability of billing conversation between trolleys and billing counters. Datta et al. [6] emphasized consumer experience enhancement by leveraging RFID for quicker checkout and stepped forward retail control.

In parallel, Fahad et al. [7] proposed an IoT-based totally RFID purchasing cart able to connecting to the cloud for real-time information updates and analysis. Their version provided a scalable solution for large retail shops. Garg et al. [8] implemented a comparable machine using Arduino, wherein each item's fee became displayed on a virtual display screen as merchandise had been delivered or removed from the cart.

Wolniak et al. [9] explored virtual transformation in retail environments via analyzing how technology inclusive of AI, AR, and RFID beautify patron stories and streamline keep operations. Their overview installed a basis for integrating smart automation in the retail quarter. Complementarily, Wang et al. [10] investigated RFID-based totally fabric identification structures able to recognizing product traits past identity codes, opening pathways for enhanced item popularity in smart carts.

Vlachos [11] supplied an extensive review of RFID-enabled grocery store structures, that specialize in automatic charge and stock tracking mechanisms. The observe recognized how RFID can revolutionize checkout methods and actual-time stock monitoring. Liciotti et al. [12] evolved a consumer analytics framework the use of digital camera networks to music purchaser conduct, supplying insight into combining sensor networks with clever shopping structures.

Chabane et al. [13] contributed to customized purchasing through imposing gadget getting to know algorithms for product hints based totally on client choices. in addition, Narayana Kumari et al. [14] supplied a machine-learning-driven eating regimen advice machine, which could complement clever buying carts by using guiding users in the direction of more healthy choices.

Muthukumar et al. [15] analyzed nutritional content material in processed foods the use of information mining techniques, contributing to the integration of health awareness in buying structures. Sree et al. [16] evaluated the accuracy of nutrient claims in Indian e-trade food merchandise, imparting a facts foundation for fitness-orientated recommendation engines in smart trolleys.

Kapoor et al. [17] proposed anomaly detection in retail environments the usage of mobile robots, suggesting a destiny where autonomous structures accurate shelf misplacements and stock mismatches. Rukundo et al. [18] surveyed demanding situations and technologies in autonomous retail structures, emphasizing the position of sensors, cameras, and RFID in enabling cashier-less operations.

Budiyanto and Muslim [19] presented an in-depth analysis of RFID-based total inventory systems, pointing out issues in data synchronization and cost reduction. Swedberg [20] showed how integrating AI and RFID is keeping retailers to combine smart insights with real-time analytics for better performance and customer satisfaction.

All these studies point out a clear transition from simple RFID billing systems to smart, IoT-sustained, and machine learning-advanced retail automation. However, most of the preceding literature typically deals with billing automation and inventory tracking, with very little attention paid to the integration of dietary guidance, cloud synchronization, and customer analytics. The proposed system aims to close this gap by using Raspberry Pi pack W for real-time billing, data communication, and intelligent analysis of product data.[20] In a preceding have a look at, R. Patil et al. [1] provided an embedded device-based totally electronic vote casting machine developed the usage of the 8051 microcontroller. The machine centered on improving vote casting accuracy, safety, and reliability via microcontroller-based totally manage and liquid crystal display interfacing. This paintings furnished a realistic foundation for imposing low-fee and efficient embedded answers for actual-time packages.[21]

III. Information

The technological revolution and the rising adoption of the Internet of Things (IoT) have a great impact on the retail industry that led to the development of smart and automated systems. In many stores and malls, customers still use old-fashioned carts and go through the manual billing process that consists of scanning barcodes at the counters. This manual method produces long lines, slow service and billing mistakes most of the time. Customers cannot keep track of their total spending or get the nutritional information of the products they are buying at the same time. Modern consumers want, faster, more transparent and contactless shopping experiences, then the role of intelligent automation in retail has become unavoidable. The ESP32-based Intelligent Smart Trolley suggested is a ground-breaking product that not only streamlines the billing process but also transforms the classic mobile cart and informs customers about the nutritional values of the products they are purchasing. The system incorporates RFID technology, which means that the products are automatically identified and, in this way, the whole process of barcode scanning is rendered useless. A unique RFID tag is attached to each product, and it is read by the reader module linked to the trolley every time the product is either added to or removed from the trolley. The information will then be transmitted to the ESP32 controller, which, in turn, will check the local or cloud database to obtain the product's details (name, price, and nutrition content). Through the Wi-Fi connection, this information will be directed to the mobile app or cloud interface where customers will see their total bill and nutrition summary in real-time.

Thus, the trolley is very user-friendly due to its DC motors that drive the trolley and make its automatic movement possible, and an IR or RF-based remote control can manage this movement. It not only lessens the physical exertion but also makes the system applicable to users of any age. IR sensors are there to help in the detection of obstacles to avert a collision, and the trolley has a buzzer that produces a sound to notify users in case of scanning duplicate or unauthorized products. The whole system receives power from a rechargeable battery, which implies that the trolley is portable and can work independently without the need for constant connection to external power sources. The IoT capabilities of the system, facilitated by the ESP32, not only provide wireless communication but also ensure that there is always a direct connection between the cloud servers or mobile devices. This integration offers users the convenience of accessing physical billing, storing data in the cloud, and making cashless payments via UPI or QR code transactions. In addition, the proposed system is equipped with a nutritional analysis feature that gives information about the calories, fat, sugar, and protein content of the items one has purchased. This not only promotes the act of purchasing good health-related products but also provides users with a chance to make better-informed decisions in terms of their diets.

In the future, ML algorithms could be applied to suggest personalized product options according to past shopping and nutrition goals.

In summary, the entire Intelligent Smart Trolley system presents a solution for retail automation that is efficient, easy to use, and scalable. It does practically nothing but human intervention, hence it has low operational costs, very high accuracy, and smart, connected, and health-oriented shopping experience for the customers. The combination of RFID technology, ESP32-based control, IoT connectivity, and machine learning-based nutritional computation makes this system in line with the goals of Industry 4.0 and contributes to the development of smart retail ecosystems and automated shopping environments.

A. *Methodology*

The process of creating the Intelligent Shopping Trolley emphasizes the application of RFID technology with a Raspberry Pi Pico microcontroller to establish a way of billing in retail. This project consists of both hardware and software components to collate the information for real-time billing and inventory management.

B. *System Overview*

system consists of a smart trolley that will have: An RFID reader that detects products. RFID tags attached to all products with a unique IDs and price information. A Raspberry Pi Pico microcontroller to process data from the scans. An LCD display, or an interface on a mobile application, that will show the current total bill. An optional Wi-Fi module for connecting to an online payment gateway and updating the inventory database. When a customer puts an item in the trolley, the RFID reader scans the tag, and the Raspberry Pi Pico receives the data from the tag and retrieves the product information from a database that was already prepared. The customer will have a total bill calculated in real time.Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation. Do not mix complete spellings and abbreviations of units: "Wb/m^2" or "webers per square meter", not "webers/m^2". Spell out units when they appear in text: ". . . a few henries", not ". . . a few H". Use a zero before decimal points: "0.25", not ".25". Use "cm^3", not "cc".)

C. *Working Principal*

The proposed Intelligent Smart Trolley that is built around the ESP32 platform is a comprehensive solution for a retail environment that uses IoT, RFID, and embedded control technologies to automate product identification, billing, and trolley mobility. The main idea behind this project is to replace barcode scanning with an automatic identification technique using RFID for the whole process and to manually control the trolley's movement via an IR remote through motor controlling circuit. Every item in the retail store comes with a distinctive RFID tag that bears the item's identification information. When a customer places an item in their trolley, the trolley's RFID reader gets the tag and transmits the product's unique ID to the ESP32 microcontroller.

The ESP32 very quickly gets the tag ID and it retrieves the related product details like the name, price, and nutrients (calories, fat, sugar, and protein, etc.) from a database that is either pre-stored or accessed via Wi-Fi connected to a cloud server. Processing of the data is performed and then it is wirelessly sent to a mobile or web interface where the user can see a real-time update of the purchased products and the total bill. If a product is removed from the trolley, the system automatically refreshes the list by deducting the item's price and nutritional values. The buzzer module gives instant feedback by notifying the users when an RFID tag that is either unregistered or a duplicate is detected, thus ensuring the system's reliability and preventing theft. Mobility of the trolley is accomplished through the use of DC motors which are linked to the ESP32 via a motor driver circuit. The trolley's direction and speed can be manipulated from afar with the help of an IR-based remote control. Furthermore, the trolley can be operated in all four directions without any physical labor. Besides that, infrared sensors that are mounted in the front and on the sides of the trolley can recognize any object that is in the way and they will stop the motors to avoid a collision automatically. Thus, it is very safe and autonomous operation.

The whole system and more, such as the ESP32, RFID reader, IR sensors, and motors, receive power from a battery that can be recharged, which makes the trolley fully portable. The Wi-Fi capability of the ESP32 also allows real-time synchronization of the billing data with the store's cloud server, enabling automatic inventory management. When the shopping process is complete, the total bill is displayed on the user's mobile interface, and payment can be made through digital methods such as UPI or QR code scanning.

1) Product Detection: RFID reader detects items whenever they get added or taken out.

2) Data Processing: ESP32 receives product data and generates billing and nutritional information.

3) Display and Sync: Data gets wirelessly transmitted to a mobile/cloud interface using Wi-Fi.

4) Mobility Control: Trolley movement is controlled by an IR remote; IR sensors are used to avoid accidents.

5) Alerts and Payment: Buzzer signals for unauthorized products; payment is done online.

Hence, the functioning of the smart cart showcases automation, IoT connectivity and mobility integration, thus providing a complete, intelligent and user-friendly retail experience.

D. Communication Flow

1) Input Stage: RFID reader reads tag information.

2) Processing Stage: Microcontroller recognizes product and calculates billing.

3) Output Stage: The display shows the item's details and the total amount.

4) Transmission Stage (optional): The data is sent to the backend or mobile phone for record keeping and payment, as per the user's support.

In figure 1 illustrates the block diagram of the IoT-based totally intelligent clever Trolley device. The gadget is centered across the ESP32 microcontroller, which serves as the primary manipulate unit. The RFID reader module detects gadgets by using scanning the RFID tags connected to merchandise. once scanned, the object data consisting of name, charge, and nutritional info (like energy, fat, and sugar) is processed and displayed on the IoT dashboard via c084d04ddacadd4b971ae3d98fecfb2a. The motor driver (L298N) controls the DC automobiles, permitting automatic

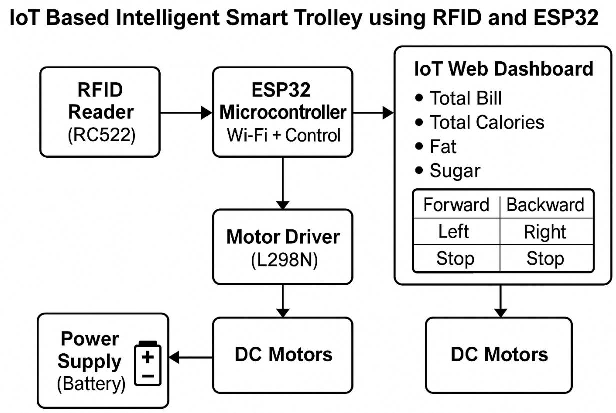

Fig. 1. Block Diagram of IoT-Based Intelligent Smart Trolley System

trolley movement in ahead, backward, left, and proper guidelines as commanded remotely thru the dashboard interface. the combination of automation and IoT ensures touchless billing, actual-time information show, and an more desirable purchasing revel in.

IV. Experimental Setup and Implementation

The proposed system underwent testing and evaluation based on a prototype model of the smart shopping trolley. The goal of the experimental arrangement is to verify the performance of the automated billing process, assess the accuracy of the RFID detection, and also examine.

This determine gives Fig 2.the hardware shape of the clever Trolley. It consists of the RFID reader (RC522) for product identification, the L298N motor driving force module for controlling DC motor movements, and battery devices for strength supply. All additives are interconnected and managed thru the ESP32 microcontroller to acquire automation and IoT integration.

A. Hardware Components

The hardware parts establish the physical support and functional foundation for the suggested Intelligent Smart Trolley. Every part has a critical importance in detecting, controlling, driving, transmitting information, and providing notifications. The main hardware parts are as follows:

1) ESP32 Microcontroller: Functions as the system's chief controller, processing data from all sensors, RFID devices, and motor drivers. It also supports Io-Fi and Bluetooth for IoT and real-time communication, respectively, as its built-in capabilities.

2) RFID Reader and Tags: The RFID reader identifies the unique IDs of the products that are tagged with RFID and are placed in the trolley. Product ID and billing information are forwarded to the ESP32.

3) Infrared (IR) Sensors: Their main purpose is to detect obstacles and avoid collisions. They work in tandem with the trolley to ensure safe passage in the shopping area.

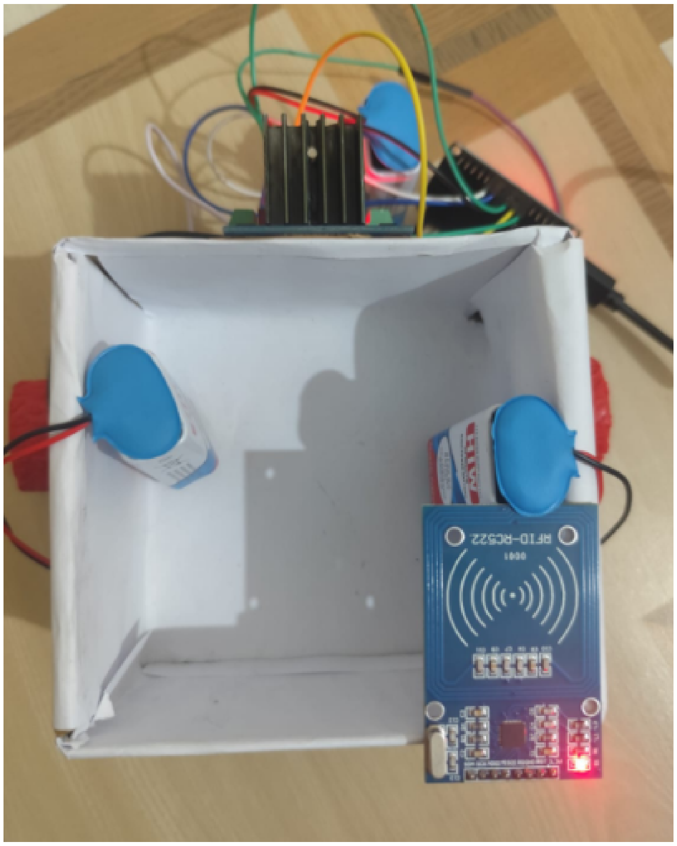

Fig. 2. Hardware implementation of Smart Trolley showing RFID reader (RC522), motor driver (L298N), and power supply.

4) DC Motors and Motor Driver (L298N): They allow the trolley to move in all directions. The motor driver connects the motors to the ESP32, thereby regulating speed and direction depending on the remote input.

5) IR Remote and Receiver: They give the users the ability to control trolley movements - forward, backward, left, or right - in a wireless manner, thus making the operation simple and convenient.

6) Rechargeable Battery: It is responsible for powering the ESP32, sensors, and motors. Thus, it makes the system portable and continuous in operation without the need for external power, as it can supply power to all components.

This fig 3. illustrates the evolved clever Trolley prototype related to the IoT net dashboard. The ESP32 microcontroller collects statistics from the RFID module and different sensors, methods the entire invoice, calories, fats, and sugar values, and transmits them to the internet interface. The dashboard also allows faraway manipulate of trolley movement via motor manage buttons consisting of ahead, Left, proper, and opposite.

B. Software Components

The Intelligent Smart Trolley software based on ESP32 takes care of the entire operations like data gathering, product finding out, and calculating billing to communicating with outside interfaces. The critical software parts are listed below:

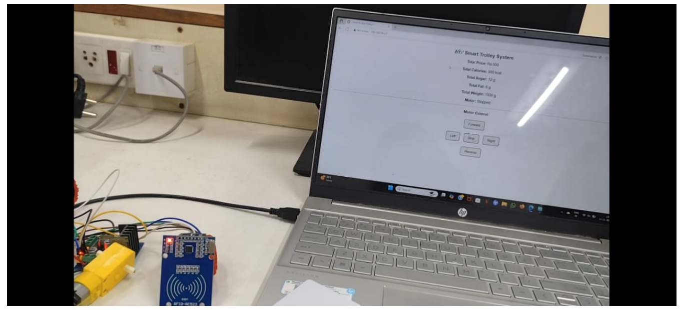

Fig. 3. Implementation of the Intelligent Smart Trolley using RFID and ESP32 with web-based control and monitoring

1) Arduino IDE:

This is the main development environment for programming and debugging the ESP32 microcontroller.

The firmware is written in the Embedded C/C++ and uploaded to the ESP32 through the application.

2) ESP32 Firmware: It controls the data from the RFID, IR sensors, motors, and the buzzer. He uses dual-core processing for multitasking—one core for sensor handling and the other for network communication. It implements interrupt-driven programming for a quick response to sensor and remote inputs.

3) Machine Learning Integration: Future extension using ML models (TensorFlow Lite or Scikit-learn) for nutrition prediction and personalized suggestions. The model that has been trained operates on a server or a cloud platform with the results being transmitted to the trolley through Wi-Fi.

4) Error Handling and Security: Routines for the recognition of duplicate or invalid RFID tags are included. Watchdog timers are employed to avoid system getting stuck and to guarantee that the operation is reliable. Network disconnection handling is put in place to maintain continuous system uptime.

5) Data Synchronization:

Trolley data is synchronized with the cloud or mobile app in real time. The system makes sure that the updates of the inventory and the transaction history are kept accurate.

C. System Interfacing

The RFID reader talks to Raspberry Pi Pico using the SPI protocol. I²C interface is utilized for LCD display, and the HX711 module is connected via GPIO pins for analog-to-digital conversion of weight information. All modules have a common ground reference and work at 5V.

In operation, the reader picks up an RFID tag located within range and sends its UID to the Pico. The microcontroller asks for the associated product from the database, calculates the running total, and shows it on the LCD. On removal of an item, the system recognizes the tag disappearance and adjusts the bill accordingly.

D. Testing Procedure

Experimental testing was performed in a controlled environment approximating a small retail store. 50 RFID-tagged items were utilized to test the system. Every trial involved removing and adding products in various combinations to imitate actual shopping habits. The following were noted during each trial:

Tag detection accuracy

Billing correctness

Response time (latency between the addition of items and the update on display)

False positive/negative rates of detection

Several experiments were performed in batches:

Case 1: Low case with 1–3 items

Case 2: Medium case with 4–10 items

Case 3: High-stress case with 15–30 items

Each case was also run 10 times for the sake of statistical consistency.

E. Performance Evaluation

The performance of the system was measured using quantitative measures such as Average Response Time (ART), Billing Accuracy (BA), and Tag Detection Accuracy (TDA). From the experiments, the average detection accuracy was found to be more than 97

V. Advantages and Disadvantages

A. Advantages

1) Automated Billing: By applying RFID technology, the system does away with manual barcode scanning completely thus it cuts down the billing time and human dependency at the same time. The customers can now automatically finish their checkout process with no need to queue up.

2) Wireless Connectivity and Cloud Integration: The wirelessly connected ESP32 with its built-in Wi-Fi capability delivers uninterrupted data exchange between the trolley and the cloud server. Thus, real-time billing, inventory management, and product information synchronization are possible.

3)Smart Mobility: The use of DC motors coupled with remote-controlled navigation brings about effortless movement of the trolley, leading to user comfort, particularly for the elderly or differently-abled customers.

4)Collision Avoidance: Infrared sensors work by detecting any obstacles that would be in the way of the trolley and they do this by automatically stopping the motors thus very gentle and safe movement in the already crowded retail areas.

5)Enhanced Security: The buzzer acts as a warning signal to the user whenever there is a case of duplicate, unauthorized, or unregistered RFID tags, thus inadvertently leading to the prevention of theft and the maintaining of system accuracy.

6) Energy Efficiency: The whole system runs on a rechargeable battery, hence it is portable and energy-efficient, plus it is a way of preventing the need for constant external power supply.

B. Disadvantages

1)Initial Setup Cost: Retailers have to initially invest more since the RFID tags need to be placed on every product, and electronic modules have to be integrated into different trolleys.

2) Limited RFID Range: The system has been equipped with an RFID reader that can only detect objects within a range of 2-5 cm, thus accurate scanning may necessitate the proper arrangement of products inside the trolley.

3) Battery Dependency: The battery determines how long the system can operate continuously; recharging the battery every time it is low is a necessity in order to keep the system working without any interruption.

4) Maintenance Requirements: RFID readers, IR sensors, and motors may need to undergo regular maintenance or calibration as parts of the process of assuring the company under their respective performance states.

5) Interference and Signal Issues: RFID reading systems may have interference problems sometimes caused by metal packaging or the overlapping of tags, which results in misreads or missed items.

6) Limited Mobility Speed: The trolley using DC motors and IR-based remote control might not be able to travel at fast speeds or engage in completely autonomous navigation without integrating advanced sensors to its system.

C. Future Scope

The Intelligent Smart Trolley system that has been proposed, is indeed a remarkable advancement in the direction of automated retail shopping that would be entirely without any human contact. Nevertheless, there are still many avenues for the system to be eventually improved and expanded on. One of the most significant ways forward is the combination of AI and ML for making predictions and giving personalized recommendations based on such predictions. The system would be analyzing the customers' buying patterns and making suggestions like healthier alternatives, favorite labels, or budget-friendly ones which in turn, would lead to customer satisfaction and improved sales.

The system could also be improved by incorporating voice recognition along with control systems so that customers can talk to the trolley and issue commands. It would thus be easier for old people and those with disabilities to use the system. Likewise, the trolley could also bring in computer vision and image processing technologies for the purpose of identifying items not tagged with RFID in addition to the already existing cameras and object detection algorithms. This, in turn, would make the system capable of operating in areas where RFID tagging of all products is not practicable. For the subsequent versions of automatic navigation, it would be an option to use a combination of IR sensors with ultrasonic sensors, LiDAR, or GPS modules. Consequently, the trolley would be able to trail customers or move within the store along the predefined routes automatically without the need for manual remote control. The merging of mobile applications with the trolley could further amplify the usability by allowing features like trolley tracking, remote billing, and e-receipt generation.

A cloud-based retail management platform can already be connected to the system so that the store managers can observe the real-time inventory, the customers' activities, and the energy consumption of every trolley. What's more, using renewable energy resources, like small solar panels, can help not only prolong battery life but also make the usage of energy more efficient.

Then again, supporting the coordination of multiple trolleys and centralized store dashboards could scope out large-scale retail environments that can handle more than one smart trolley at the same time. Not only that, but it also would be a significant factor in traffic control and automation at the business level in the whole store. In a nutshell, as a result of constant research and the development of technology, the Intelligent Smart Trolley can be transformed into a completely autonomous, AI-driven, and eco-friendly retail solution that points towards the future of smart shopping as the next generation.

VI. Conclusion

The Innovative Smart Trolley that makes use of ESP32 is able to fully automate the shopping and billing process thanks to the merging of RFID technology, IoT connectivity, and sensor-based mobility control. The entire process of manual scanning of barcodes is totally eliminated and in addition to this, the check-out time is greatly reduced as all the products are detected and bills are issued in real-time. The trolley is not only capable of moving according to the control system, detecting obstacles, and displaying nutritional information but also improves the user's experience and makes the shopping process more efficient. Using the ESP32 microcontroller not only results in low-cost implementation, high processing power, and wireless communication support but also gives the advantages of low-cost implementation. To conclude, this project is the start of smart retail automation, which implies a more seamless and contactless shopping experience for customers.

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