Design and Implementation of a Low-Power, Cost-Effective RFID-Based Smart Shopping Trolley with Real-Time Automated Billing for Small-Scale Retail

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***Abstract*—**The growing trend of retail automation has necessitated the demand for a cost-effective and efficient billing system, especially for small and medium retail outlets. Traditional checkout systems suffer from long queues, manual scanning mistakes, and no real-time monitoring of expenditures. The design and implementation of a portable, low-power RFID-based smart shopping trolley which can assist with real-time automated billing without any assistance from the operator, is presented in this paper. The system is based on an Arduino Nano microcontroller, RC522 RFID reader, I2C controlled 16x2 LCD display and a dedicated push-button for interactive item removal. A passive RFID tag is attached to every product and when scanned the information about each product and the new total is instantly displayed. Operating current is less than 70 mA, the trolley is powered by a rechargeable 18650 Li-ion battery with Type-C charging. The system achieved a 100% read success rate across 10 product categories, and an average read time of 47.6 ms. The proposed system reduces the average checkout time from 8-9 min in conventional checkout systems to 1-2 minutes making this system a cost effective and suitable for small-scale retail systems.

***Keywords*—**Smart shopping trolley; Automated billing; Retail automation; Smart retail; RFID technology.

I. INTRODUCTION

Automation has been a vital part of the business world, particularly in retail shops, where supermarkets and shopping malls are constantly looking for means to improve the client experience with less time and expense. Although barcode scanners and self-check out kiosks have been introduced, the traditional billing systems still introduce significant bottlenecks. Queues are formed as items are scanned one by one by cashiers, which results in time being lost, congestion during peak hours and incorrect pricing and item entry. Moreover, these systems don't offer any real-time feedback and customers cannot keep track of their spending while they are shopping. To overcome these problems, the novel retail technologies are explored worldwide [1], [4], [9]–[11]. Although advanced tools, like camera-based object recognition and scanning of mobile applications exist, they are usually rather prohibitive or involve complex implementation that makes them inapplicable to smaller facilities [2], [5], [6], [13]. As a result, there is a growing demand for a simple, portable and affordable system that can allow customers to control their billing in the process of shopping. Therefore, improving the efficiency of retail billing systems has become an important research focus in recent years.

Problem Statement: Current automated billing systems have serious drawbacks. Camera-based deep learning systems are accurate but require high processing power and are too expensive for small retail stores. Many existing systems are not interactive (e.g. real-time removal of items; audio-visual feedback during shopping) and RFID-based systems are a relatively inexpensive solution. Furthermore, a significant issue for retailers is theft prevention, and most affordable solutions don't cover this area or offer item verification. There is a growing need for a portable and affordable smart trolley for small and medium retail outlets. This paper proposes and designs a smart shopping trolley, which relies less on manpower, reduces human errors, and at the same time encourages customers to participate in managing their purchases. The checkout gets updated in real time as the customer shops, thus eliminating waiting time. The rest of the paper is as follows: Section II describes the literature review of billing systems. The major contribution of the paper is proposed in Section III. The result of the proposed system is discussed in Section IV and the conclusion is in Section V.

The novelty of the proposed work lies in integrating low-cost, battery-based operation, real-time billing, item removal functionality with audio-visual feedback into a single stand-alone, dedicated system for resource-constrained small retail spaces [12], [13], [18]. Unlike conventional RFID-based systems that depend on centralized billing counters or expensive vision-based solutions, the proposed design provides real-time billing through an on-board LCD, allowing customers to monitor their purchases throughout the shopping process [9]–[11], [13]. A dedicated push-button based item removal

feature enables users to remove mistakenly scanned products instantly without requiring manual intervention. The power supply of the system is a rechargeable 18650 Li-ion battery with the charging module Type-C, which is portable and can be deployed easily. The simplicity in the hardware architecture, its low power usage, its ease of implementation, and its cost effectiveness make it an appropriate solution for the small and medium scale e-retail stores, and also lays the groundwork for future integration with IoT and cloud-based retail systems. Moreover, the prototype was experimentally tested across ten product categories, achieving a 100% read success rate and an average read time of 47.6 ms, demonstrating reliable real-time performance. Its affordability, portability, and low power consumption make it well suited for small and medium-scale retail stores where advanced automated checkout systems may be prohibitively expensive. This work has contributed, in particular, as follows:

i. Design and development of a portable RFID based Smart shopping cart with simple components (Total cost of Hardware: Rs 2500).
ii. Developing a real-time billing system that allows customers to use a push-button to remove incorrect items and correct the billing immediately.
iii. Audio-visual feedback (buzzer and LED) to enhance interaction and error notification.
iv. Experimental proof of 100% read success rate and reduction in checkout time from 8-9 minutes to 1-2 minutes.
v. Proposal for future enhancement using load cell-based weight verification to address theft prevention, a critical gap identified in recent surveys.

II. LITERATURE REVIEW

The usage of automatic billing systems and smart shopping trolleys has been observed gradually over time. Researchers have considered different approaches, such as vision-based recognition, RFID technology, IoT systems, mixed embedded systems, and real-world use cases.

A. Vision Based Methods

Recent research has focused on deploying vision and AI to enhance how products are identified in smart shopping carts. The system that integrated IoT and cameras was structured, where the camera automatically identifies products, making the checkout process easier, faster and helping to reduce human errors [5], [6]. More innovative strategies have used deep learning models like YOLOv10, which has significantly improved the speed and accuracy of self-checkout, even in different lighting and store environments [17]. The deployment of edge-based deep learning has also demonstrated the feasibility of performing vision-based processing closer to the application environment, reducing dependence on centralized computational resources [16]. Some systems combined image processing with mechanical arms, allowing the carts to not only detect items but also handle them during checkout, making the process efficient. Industrial projects like Caper, Grabango, and Amazon Dash/Go used vision sensors and AI in supermarkets, enabling fast, touch-less shopping experience [3]. Earlier vision systems using image processing and feature recognition helped develop better item classification and billing automation, forming the basis for today's AI-driven models [14], [20]. Simple vision algorithms have been demonstrated to be cost-effective and to work well even in small scale projects, as illustrated in these results [5].

B. RFID and IoT Enabled Systems

The automated trolley has been a favored and reliable automated method, and the use of RFID technology has been popular. Dual beacons and weight sensors were utilized in smart carts to enhance security and reliability of the system [7]. However, a number of student and research designed, low-cost, RFID carts demonstrated the ease with which these systems could be utilized in small retail outlets [10], [11]. Flexible software and RFID scanning could be used to achieve scalable billing systems using the IoT frameworks [8]. This recent smart-retail research has also highlighted the importance of incorporating IoT technologies to enhance connectivity, automation, and the overall shopping experience [20]. Improved communication enabled product information to be transmitted between the shopping cart and the billing system in real time, minimizing delays during checkout [9], [11]. Other solutions introduced voice control to trolleys fitted with RFID scanners to make them user friendly and accessible [11]. The large scale tests showed that the RFID carts could manage a large number of transactions in large stores, which are scalable to large retail environments [9]. Despite this, not all RFID systems have buttons to remove items or feedback mechanisms, and few pay attention to theft prevention.

C. Hybrid and Embedded Approaches

Hybrid designs provided better real-time billing solutions with a combination of embedded processors, sensors and vision systems. Combining software and hardware in automated shopping carts, while using image processing, was shown to enhance the efficiency in billing systems and was demonstrated using Python programming [5] and [6]. A few studies considered trolleys equipped with microcontroller, RFID, load sensors, and network interfaces of updating billing amounts in real-time, ensuring data consistency with the main servers [4], [8], [13].

Large systems using RFID to enable faster communications, thereby speeding up checkout counters in large stores [9]. Rather, hybrid solutions with load sensors and embedded processors performed item weight checks as well, ensuring accurate billing even when RFID tags are malfunctioning [7], [15].

D. Industry Implementation and Emerging Trends

Research ideas into common systems in real world use. Caper, Grabango, Amazon Dash/Go are sensor-based, sensor and internet connected and sensor and AI based products, which have been used in real stores to facilitate easy checkout, providing seamless experience [2]. Robots picking and placing goods demonstrated the automation of the goods handling process, along with billing, which would make shopping easier for customers and give them an accurate solution [5], [19]. Adopting deep learning techniques such as YOLO significantly boosted the precision of quick and error-free object detection [2]. The navigation, integration with the app, and interactive billing screens, for instance, enhanced the shopping experience [18]. All these examples highlight the smart shopping cart as a real product, and how vision, RFID, IoT and embedded

systems are transforming the future of retail automation [20]. Based on this review, the following research gaps are identified:

E. Summary of Research Gaps

The literature review shows that while smart trolley research has advanced, key gaps remain:

i. Cost: Vision-based systems are too expensive for small retailers.

ii. Interactivity: Most RFID systems lack item removal buttons and real-time feedback.

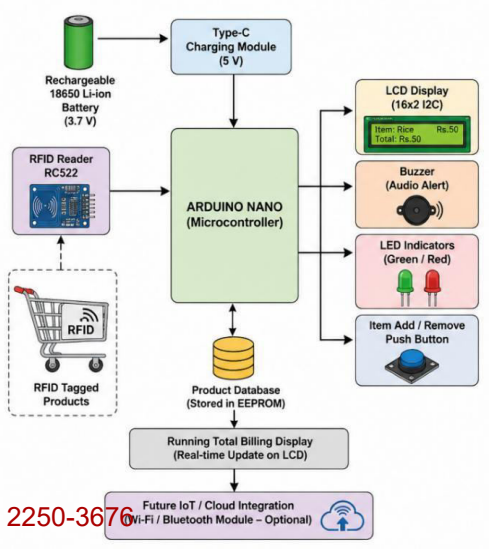
iii. Security: Theft prevention and item verification are still unsolved.

iv. Portability: Many systems need fixed infrastructure or external power.

This paper addresses these gaps with a portable, low-cost RFID trolley with interactive features and a proposed weight-based verification mechanism.

III. PROPOSED METHODOLOGY

The Smart Shopping Trolley with Automated Billing is designed to overcome the limitations of the traditional checkout systems by automating the customer interface. Every product in the trolley will have an RFID tag, which the microcontroller installed in the trolley reads in real time. The total amount of purchase is displayed simultaneously on an LCD screen and enables customers to keep track of their purchases. Interaction buttons enable customers to add or remove items quickly eliminating errors that cut the checkout time and improve the overall shopping experience. The system is well designed and can be integrated in the future with IoT or cloud systems to enable further functionalities such as inventory monitoring, dynamic pricing, promotions management, and consumer behavior analytics. The power consumption of the proposed system was measured by using a digital multimeter which is placed in series with the battery supply. Under normal operating conditions (continuous scanning and display updates), the system drew a stable current of 65–70mA. This is significantly lower than existing smart cart systems that consume 80–100mA. The low power consumption is attributed to the use of passive RFID tags (no external power required) and the efficient Arduino Nano microcontroller. With a 2600mAh battery, the system can operate continuously for approximately 37-40 hours on a single charge, making it suitable for full-day retail operations.



A. System Architecture

The Smart Shopping Trolley is built around an Arduino Nano microcontroller serving as the central processing unit.

Fig.1. Architecture of the Proposed RFID-Based Smart Shopping Trolley System

It consists of five main components: (i) an RC522 RFID reader module to identify items, (ii) a 16×2 LCD with I2C interface for displaying real-time information, (iii) a push button module for item removal, (iv) a buzzer and LED module for visual and auditory feedback, and (v) a rechargeable 18650 Li-ion battery with Type-C charging module for mobile power. To keep wiring to the minimum the LCD uses I2C protocol, and the RFID reader is linked to the Arduino using SPI protocol. Once a tag has been placed in the vicinity of the reader, the tag ID will be read and compared with the product database which is stored in the memory of the microcontroller. Then the item name and price will appear on the LCD, and the running total will be updated immediately. This will result in low power consumption, easy maintenance and scalability for future enhancements, because of this modular architecture. Fig.1. shows the architecture of the Proposed RFID-Based Smart Shopping Trolley System.

B. Working Principle

The operation of the proposed system consists of a series of steps as follows:

Step 1-Initialization: The Arduino Nano initializes all the peripherals attached to it such as the RFID reader, LCD, buzzer and LED when it is powered on. A welcome message is displayed on the LCD.

Step 2-Item Detection: The RC522 reader creates a magnetic field which induces power to the passive RFID tag, and the unique ID of the tag is sent to the microcontroller.

Step 3-Validation: The microcontroller checks the ID received with a pre-stored product database. An invalid tag or an unrecognized tag will lead to an error message and an alert will sound on the buzzer.

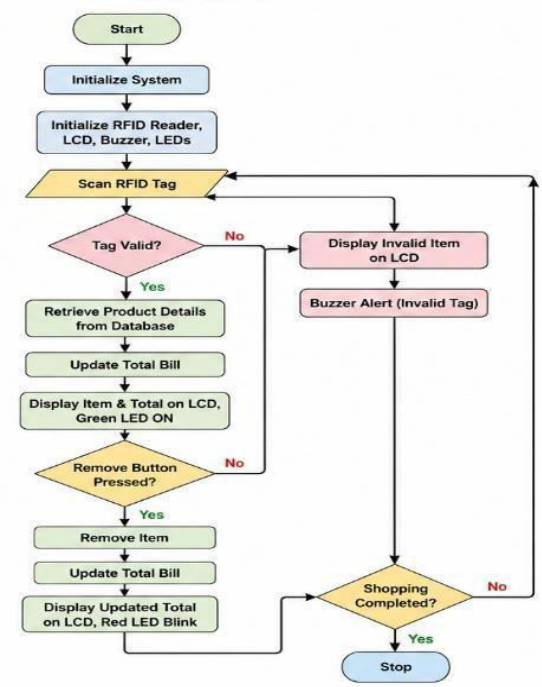


Fig.2. Flow Chart of proposed methodology

Step 4-Billing Update: Retrieves the product name and price associated with valid tags and updates the running total. The LCD shows the information about the item and the updated total.

Step 5-Item Removal: When the push-button is pressed during scanning of a tag, the system assumes that the item is being removed, accidental presses are minimized by requiring simultaneous button press and RFID scan. The price of the item is subtracted from the total and the LCD verifies the subtraction.

Step 6-Feedback: The buzzer and LED give instant feedback for each action (addition/removal), making the product user friendly.

Step 7-Session Completion: This step is repeated for each item until shopping has been done. The total amount is shown on the LCD for payment at the end.

C. Hardware Requirements

The Smart Shopping Trolley consists of simple yet essential hardware components that enable portable and real-time operation. The hardware design and component layout of the proposed system is shown in Fig. 3.

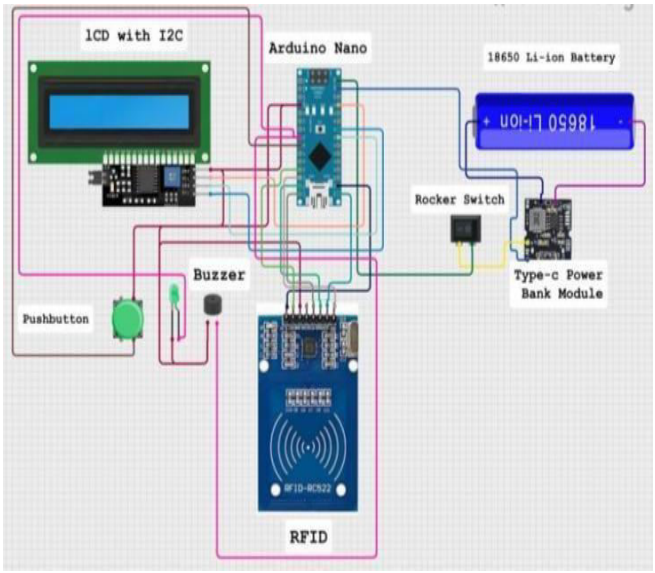


Fig.3. Component Layout for Smart Shopping Trolley

The total cost of the proposed prototype is approximately ₹2500, making it affordable for small and medium-scale retail stores.

TABLE I. Component-wise cost breakdown

Component	Quantity	Approx. Cost (₹)
Arduino Nano	1	400
RC522 RFID Reader	1	250
RFID Tags (pack of 10)	1	300
16×2 LCD with I2C	1	250
18650 Li-ion Battery	1	350
Type-C Charging Module	1	150
Buzzer + LED + Push Button	1 set	100
Rocker Switch + Wires + PCB	-	200
Trolley Frame (reused)	1	500
Total	**-**	**Approx ₹2500**

This cost is significantly lower than vision-based systems and existing smart carts, which typically cost ₹4500–6000 or more.

D. Software Requirements

The system software was programmed using the Arduino IDE open source platform available for Windows, Mac and Linux. This code is written in C++ and loaded into the Arduino Nano using the USB. The system software is based on four major libraries that are: SPI.h for RFID communication, MFRC522.h for controlling the RC522 reader, Wire.h for I2C communication and LiquidCrystal_I2C.h for LCD interfacing. The product database which included the tag IDs, item names, and prices are stored in the microcontroller's flash memory. The software flow consists of software initialization, tag scanning, database look-up, bill calculation and feedback generation. The modular code structure enables the easy inclusion of new products by updating the database only.

TABLE II. Power Consumption Analysis (mA)

Component	Approx. Power Consumption (mA)
Arduino Nano	19
RFID Reader RC522	13–26
LCD Display	2–5
Buzzer	20
Total System	< 70

E. Power Management and Efficiency

The proposed system is designed for low-power operation. It includes a rechargeable 18650 Lithium-ion battery which provides constant voltage to the Arduino Nano and other auxiliary models. The passive RFID is also used; since they do not require internal power source, they make a significant contribution to the total decrease in the energy requirement. Table II presents the power consumption analysis of individual components.

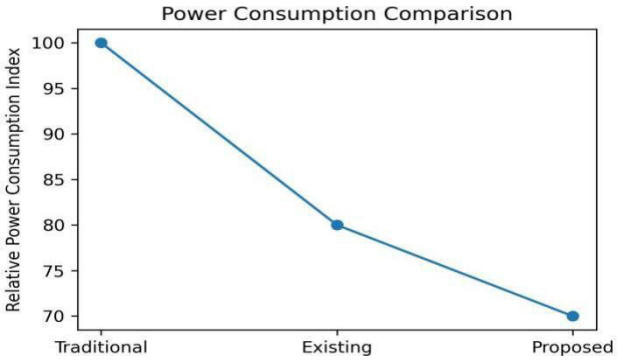


Fig. 4. Relative Power Consumption Comparison

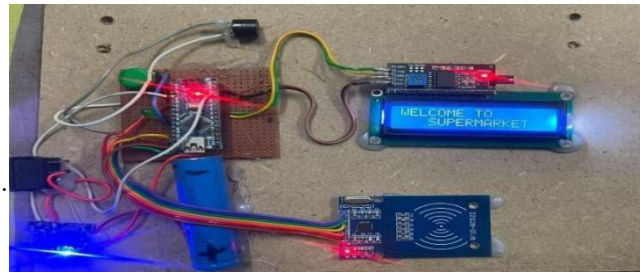
IV. RESULTS AND DISCUSSION

The Smart Shopping Trolley was tested after combining both hardware and software. The LCD then displayed the word “Welcome to Supermarket - Scan Item”, which means that the system was ready as shown in Fig 5. For verification of reliability and accuracy of the proposed system, ten different product categories were used. Five scans of each product were undertaken from different distances to

determine the percentage of products correctly read and the average read time. The system was tested 50 times for initial reliability, with more tests in different conditions planned next as the future work. The variation in read range (6–10 cm) across products is attributed to differences in tag orientation and placement relative to the reader antenna. Tags placed flat and closer to the antenna center exhibited a longer read range.

TABLE III. Performance Testing Results (10 Products × 5 Trials)

Item	Price (₹)	Read Success	Avg. Read Time (ms)	Max Range (cm)
Rice	120	5/5	45	8
Butter	51	5/5	52	7
Milk	60	5/5	48	9
Bread	35	5/5	41	10
Juice	80	5/5	55	6
Soap	45	5/5	43	8
Shampoo	120	5/5	47	7
Chocolate	20	5/5	50	9
Biscuit	30	5/5	42	8
Detergent	75	5/5	53	7
Average	-	**100%**	**47.6 ms**	**7.9 cm**



When an RFID tag like Rice is scanned, the system verified it, added the item, and updated the total on the LCD. A short green LED blink confirmed the addition as shown in Fig 6.

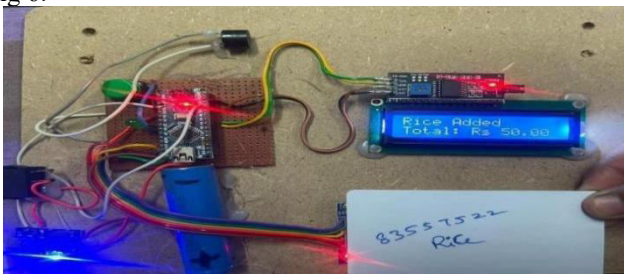


Fig.6. Adding item – Rice scanned

Fig 7 shows Butter added with total updated to Rs. 171.00.



Fig 7. Adding another item – Butter scanned

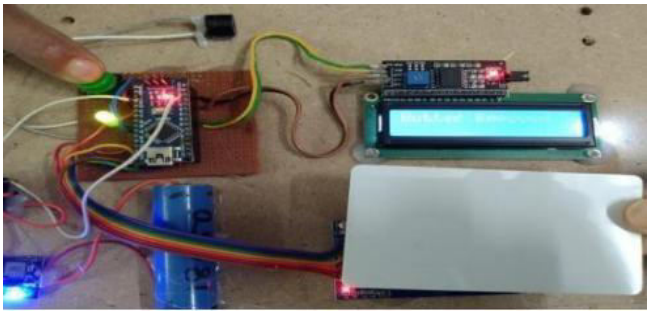


Fig.8. Removing duplicate item – Butter removed

Figure 8 shows the removal of a duplicate Butter entry, with total corrected to Rs. 251.00.

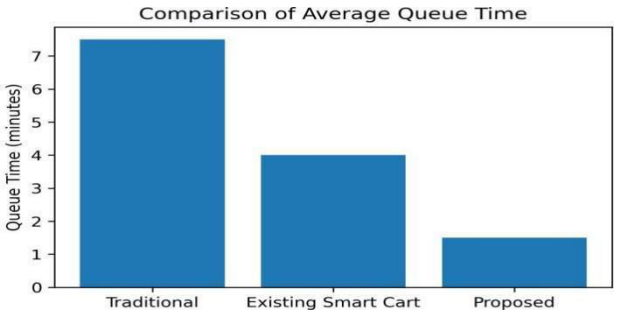


Fig. 9. Comparison of Average Queue Time for Different Billing Systems

TABLE IV. Comparison between Existing and Proposed System

Parameter	Traditional Billing	Existing Smart Cart [9]	Proposed System
Billing Method	Manual cashier	Semi-automated	Fully automated
Avg Queue Time (min)	8–9	4–5	1–2
Human Intervention	100%	45%	10%
Real-time Bill Updates	No	Partial	Yes
Approx. Power Consumption	>120mA	80–100mA	<70mA
Customer Interaction	Low	Moderate	High
Estimated Cost	Infrastructure	₹4500–6000	₹2200–2800
Read Success Rate	N/A	85–90%	100%

V. CONCLUSION

The Smart Shopping Trolley with automated billing is a successful example of applying RFID technology to automated retail checkout. It runs on a minimum current of 70mA or less and costs just ₹2500 which is affordable and suitable for small and medium retail outlets. At present, the system is only able to detect RFID tags within a short range and product-level RFID tagging is needed. Tag collision handling and integration of the inventory in the cloud will be addressed in future work.

Future work is to add a load cell sensor for weight theft detection, by making use of an ESP8266 Wi-Fi module to

connect it to the cloud for inventory, also allowing mobile payment and QR code checkout to be integrated. The enhancements will improve the system's security and scalability for usage in the real world of retail.

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