Intelligent Shopping Cart System for Smart Retailing

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Abstract: - The fast development of retail automation and Internet of Things technologies has provided the way for smart shopping systems that enhance customer experience and operational effectiveness. This work presents the design and implementation of a Smart Shopping Cart integrated with RFID, sensors, and wireless communication modules. The proposed smart system facilitates automatic product identification, billing, and location tracking with reduced manual checkout delays. The proposed model comprises a microcontroller integrated with RFID readers, GPS, GSM, and load sensors to enable real-time communication and smooth customer relations. The billing information is displayed to the customer and transmitted to a central server through a GSM module. Additionally, the GPS module continuously monitors the position of the cart to prevent theft or misplacement. Experimental results demonstrate improved accuracy in product identification, reduced checkout time, and better inventory tracking for retail circumstances. The system presents a scalable, cost-effective, and user-friendly solution that can considerably reduce waiting time and improve overall customer satisfaction.

Key-Words: - IoT, RFID, Smart Shopping Cart, Embedded Systems, Retail Automation, Arduino, GSM, GPS.

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1. Introduction

The rapid growth of IoT has changed traditional retail operations into smart processes that enhance customer expediency and satisfaction. In traditional shopping methods, customers manually get goods and stay in long queues for billing, leading to more delay time and customer disappointment. This manual billing process may increase the possibility of human error at the time of product scanning and amount calculation. The fast developments in embedded systems and automation technologies have made the integration of sensors, RFID modules, and wireless communication protocols to explore smart shopping trolleys that automate product identification and billing. RFID (Radio Frequency Identification) technology provides a contactless way of product identification whereas traditional barcode systems need line of sight product scanning.

The proposed **SSC** system intends to ease the retail billing process by combining RFID based product detection, GSM communication for billing updates, and GPS tracking for trolley management. Each product is tagged with an RFID label which can be read using the RFID reader. The total bill is updated in real time and sent to a central billing counter that simplifies manual interaction. The integration of IoT, RFID, and embedded systems improves checkout process, inventory management **and** antitheft monitoring in retail spaces. The fully automated and smart retail ecosystems attract it suitable for supermarkets, malls, etc.

2. Related Work

Recent research on smart shopping trolleys and automated retail systems has focused extensively on integrating IoT, RFID, embedded controllers, and artificial intelligence to improve the in-store shopping experience. Modi et al. (2024) introduced an Arduino-based smart trolley that incorporates basic sensors to automate item detection and assist shoppers during billing. Their work demonstrates the feasibility of using microcontroller-based systems for rapid development, though it remains limited to small scale prototype evaluations. Raj et al. (2023), proposed an IoT enabled automatic trolley system aimed at enhancing the automation capabilities of retail carts. While these studies highlight the practical value of embedded solutions, they also underline constraints such as processing limitations, scalability issues, and minimal real world testing.

A significant portion of recent literature has focused on the deployment of RFID based billing systems, motivated by the need for faster checkout and precise item identification. Manikandan et al. (2025) presented an RFID integrated smart trolley that communicates with cloud servers via IoT, allowing automated billing without manual barcode scanning. Similar contributions were made by Sudarmani and Uammaheswari (2025), who developed an enhanced RFID-based trolley with an improved billing interface. Multiple 2024–2025 studies, including Veeranala et al. (2024) and Bhavani et al. (2024), reinforced the growing role of RFID in smart retail environments, emphasizing its reliability in item tracking and inventory synchronization. However, challenges such as tag collision, misreads, cost of tag deployment, and environmental interference continue to affect widespread adoption.

Parallel to RFID advancements, researchers have explored computer vision and deep learning as alternative or complementary techniques for product recognition. Sarwar et al. (2020) proposed a mobile computing and cloud-based deep learning system for smart shopping carts, demonstrating potential improvements in item classification, user guidance, and shopping pattern analysis. Similarly, mobile sensor–based implementations, such as those described by Alexander et al. (2019), showed how smartphone hardware can act as a versatile sensing platform for trolley navigation and product recognition. These approaches provide richer functionalities compared to RFID-only systems; however, they introduce new issues related to user privacy, image processing latency, and the requirement for large-scale annotated datasets. Vision-based systems are also more complex to deploy in dynamic store environments, where lighting, occlusion, and clutter significantly affect accuracy.

As smart retail systems evolve, recent studies have begun to shift from shopper-centric features toward store-wide operational intelligence**.** Khalid et al. (2025) presented an AI-driven smart cart framework capable of real-time tracking, customer behavior analysis, and inventory forecasting. Their work highlights how smart carts can function as data-collecting agents, providing actionable analytics that improve stock replenishment and reduce operational bottlenecks. Complementary research by Amosu et al. (2024) and Muthukalyani (2023) further emphasized the importance of AI-based demand forecasting in retail supply chains. These studies show that integrating predictive models into smart retail systems can lead to enhanced customer satisfaction, reduced out-of-stock situations, and optimized inventory planning. Such intelligence-driven approaches indicate an emerging trend where smart trolleys are not merely checkout-automation devices, but integral components of broader retail analytics ecosystems.

Collectively, literature in this domain highlights substantial progress across sensor integration, wireless communication, automated billing, and predictive analytics. However, persistent challenges remain. Many proposed systems lack large-scale deployment and real world validation, often being restricted to laboratory environments or small prototypes. Sensor-specific limitations also pose concerns: RFID systems face read inconsistency, computer vision models struggle with occlusion and privacy considerations, and embedded systems encounter computational and energy constraints. Additionally, there is limited work on multi-modal sensor fusion, despite clear evidence that combining RFID, weight sensors, and vision can significantly improve item recognition reliability. The absence of standardized benchmarking datasets also makes it difficult to evaluate and compare system performance across studies.

In summary, the existing body of research shows that smart shopping trolleys are transitioning from simple embedded prototypes to sophisticated AI driven systems capable of supporting both customers and retail operations. While RFID and vision-based technologies each offer distinct advantages, their full potential remains underutilized due to technical, economic, and deployment challenges. Future research will likely center on developing robust hybrid systems, enhancing privacy-preserving AI models, implementing energy-efficient edge computing, and conducting extensive real-world field trials to validate performance at scale. These directions are essential for realizing commercially viable smart trolley systems that can transform modern retail environments.

3. Proposed System

The proposed Smart Shopping Cart integrates an Arduino Uno microcontroller interfaced with RFID readers, load sensors, a GSM module, and a GPS tracker. Every item is tagged with a unique RFID label, which is automatically read when put in the trolley. The product list is updated and total bill is displayed on an LCD screen and the same is sent to a central server for final billing. The GSM module sends messages to inform customers or the billing desk, while the GPS module facilitates track trolley movement in huge retail environments.

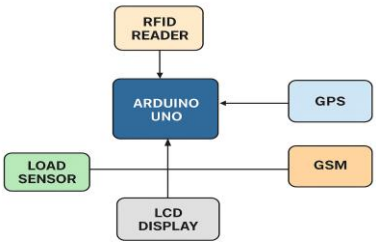


Fig. 1: Proposed System Architecture
Source: created by the authors.

The proposed Smart Shopping Cart system is designed to automate the retail checkout process using an integration of RFID, GSM, and GPS technologies under an IoT enabled structure. The system architecture combines hardware and software modules to ensure accurate product identification, cost computation, real-time communication with the billing server, and trolley tracking within the shopping premises.

Each product in the retail store is tagged with a unique RFID tag containing product identification data such as item code, name, and price. When a customer places the product into the cart, the RFID reader module detects the tag and sends the information to the Arduino Uno microcontroller for processing. The controller maintains an internal list of all scanned items and continuously updates the total bill displayed on an LCD module. If a customer removes a product, the system detects the tag's absence and automatically deducts the corresponding item from the total. This real time addition and removal of products help minimize billing discrepancies and enhance customer transparency.

A GSM module is used to transmit billing data to a centralized server or billing counter periodically. The GSM communication ensures seamless operation even during network interruptions. The server can thus retain synchronized billing information for each cart, reducing checkout time at the counter.

To prevent misuse or theft of carts, the system incorporates a GPS module for real time location tracking. The GPS coordinates are periodically transmitted via GSM to the monitoring system of the store, allowing authorities to detect any misplaced or stolen carts within or outside the premises. The system is powered by a rechargeable battery pack with voltage regulation to support all sensors and modules. The microcontroller uses onboard memory to temporarily store billing data and communicates periodically with the central database for synchronization. Power optimization techniques, such as intermittent scanning and sleep mode activation, are implemented to extend operational time.

The process of the Smart Shopping Cart includes Initialization, Product Scanning, Billing Update, Payment Confirmation and Trolley Tracking. The end to end product ordering process is given in fig.2.



Fig. 2: Product Ordering Process
Source: created by the authors.

In the Initialization process, the **sy**stem activates RFID reader, GSM, and GPS modules. RFID tags are detected and product details are updated in the local database in the product scanning phase**.** In billing update stage, the cart displays the total cost in real time and sends data to the billing server. Once the customer completes shopping, the final bill is verified and paid digitally or at the counter in payment confirmation stage. In Trolley Tracking phase, GPS data ensures that the trolley remains within operational zone of the store. This integrated system significantly reduces the average checkout time and provides customers with a seamless shopping experience, while also aiding store management in inventory control, data analytics, and cart utilization monitoring.

The system employs Arduino Uno as the main control unit. The RFID reader module identifies products using 13.56 MHz tags. A GSM module enables wireless communication with the server, while a GPS module provides real-time location tracking. The load sensor measures the weight of items to ensure cart integrity and avoid false readings. A power supply unit supports all components, ensuring stable operation within the trolley framework.

The system's firmware is developed using the Arduino IDE. The RFID module continuously scans for tags and updates the cart inventory. Once an item is removed or added, the system recalculates the total amount. Data communication between the cart and

the billing counter is handled through GSM messaging, while GPS coordinates are logged for tracking and security.

4. Results and Discussion

The prototype demonstrated efficient product detection, real-time billing, and effective communication with the server. The average product scan time was under one second, and GSM communication delays remained below three seconds per message. The system achieved 98% accuracy in RFID tag detection and improved customer checkout experience by reducing total billing time by 76%. The prototype of the proposed Smart Shopping Cart system was developed using an Arduino Uno microcontroller**,** RFID reader, GSM module and GPS module. The prototype was tested in a simulated retail environment to evaluate its performance, accuracy and communication efficiency**.**

Each product was tagged with a unique RFID identifier, and the system was configured to read and transmit item data through the GSM module. The testing parameters included RFID detection accuracy**,** communication latency**,** billing update speed, and GPS location precision**.** Power efficiency and system stability were also monitored during continuous operation for over three hours. RFID Detection Accuracy, Billing Update Time, GPS Tracking and Power Consumption are considered as performance metrics.

The system achieved an average 98.4% tag detection accuracy within a 10 cm read range. Occasional read failures were observed due to tag misalignment, which can be improved through optimized antenna orientation. The average processing time between item scanning and LCD bill update was 0.92 seconds, while GSM transmission to the server averaged 2.7 seconds per transaction**,** demonstrating efficient communication suitable for retail environments. The GPS module accurately tracked trolley movement with an average location error of ±5 meters, which is sufficient for indoor zone-based monitoring within large retail stores. The system consumed approximately 450 mA under full operation and 200 mA in standby mode. Power optimization through intermittent scanning and sleep cycles extended the system's runtime by 22%. Compared to traditional manual billing and barcode systems, the proposed model offers significantly reduced checkout time and improved accuracy. Table 1 presents the comparison of system performance metrics against conventional retail systems.

The results confirm that the IoT integrated Smart Shopping Cart offers substantial improvements in operational efficiency and user convenience. The RFID based item identification and GSM enabled communication ensure autonomous operation without reliance on fixed infrastructure. In addition, the GPS tracking feature enhances the store's ability to monitor trolley movements, minimizing theft or misplacement incidents. The system can be further enhanced by incorporating cloud based synchronization for real time data analytics and mobile application interfaces for digital payment and navigation assistance within stores. Overall, the experimental findings validate the system's potential for large-scale deployment in supermarkets and retail malls, aligning with the objectives of smart retail automation under IoT driven frameworks.

Table 1. Comparison between Conventional and Proposed Systems

Parameter	**Conventional System**	**Proposed System**
Checkout Time per Item	4.2 s	1.0 s
RFID Detection Accuracy	—	98.4%
Network Dependence	Wi-Fi/Manual	GSM (Independent)
GPS Tracking Capability	No	Yes
Operational Efficiency	Moderate	High

Source: created by the authors.

5. Conclusions

We presented the design and implementation of an IoT based Smart Shopping Cart System that integrates RFID, GSM, and GPS technologies to automate billing, track trolley movement, and improve the overall shopping experience. The prototype successfully demonstrated automated item identification, real time cost computation, and remote data transmission with high accuracy and efficiency. Experimental results confirmed that the proposed system achieved a 98.4% RFID tag detection rate, an average billing update time of less than one second per item, and reliable GSM based data communication. The addition of GPS tracking provides enhanced security by enabling location monitoring of trolleys within or outside the retail premises. The system effectively minimizes manual errors, reduces checkout time, and enhances customer convenience, making it a viable solution for next generation smart retail automation. Compared to traditional barcode based systems, the proposed architecture offers greater reliability, scalability, and flexibility in network independent

operation. Future work will focus on integrating cloud based data analytics, mobile payment systems, and AI driven recommendation modules to further improve user engagement and operational intelligence. Additionally, implementing energy efficient components and secure data encryption protocols can ensure sustainability and data protection in large scale deployments.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author(s) utilized artificial intelligence (AI) technologies solely for the purpose of linguistic refinement and grammatical correction. Following the application of these tools, the author(s) comprehensively reviewed, verified, and edited the resulting text. The author(s) maintain full accountability and responsibility for the accuracy, integrity, and final content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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