

Research Paper

An overview of RFID-controlled smart shopping cart systems for efficient supermarket checkout

Uzma Sheikh¹, Dr. Tirupati Guskula²

PG. Scholar , Professor

Department of Electronics and Telecommunications Engineering

Anjuman College of Engineering and Technology, Nagpur, Maharashtra, India

Abstract

The checkout remains the biggest bottleneck in modern retail. Manually scanning barcodes leads to long queues, cashier errors, and reduced customer satisfaction. RFID (Radio Frequency Identification) technology, combined with low-cost embedded platforms like the ESP32 and Arduino, is frequently proposed as a solution to move product identification and billing from the checkout area directly to the shopping cart. The study identifies consistent design patterns—a cart-mounted RFID reader, a microcontroller for local processing, a display for real-time billing information, and a wireless connection to a central server or database—as well as secondary enhancements such as ZigBee/Bluetooth mesh connectivity, weight sensor cross-verification, and anti-theft measures. At the same time, it highlights recurring weaknesses such as tag interference, limited scalability testing, and inadequate inventory synchronization mechanisms. Based on this synthesis, the article explains the reasons for a proposed ESP32-based smart cart system that combines an RFID scanner and an LCD display with a Wi-Fi connected server and is intended to automate billing, reduce waiting times at the checkout, and improve inventory accuracy in ongoing retail operations.

Keywords: RFID, Smart shopping cart, ESP32, IoT, Automated checkout, Retail automation, Inventory management

1. Introduction

Shopping in malls and supermarkets is now part of everyday life, but the final step – paying – is still largely manual. Cashiers scan the barcode of each item individually, check the price, and add up the total before the payment can be processed. During peak hours, this process leads to long queues, extended waiting times, and negatively impacts customer satisfaction. Manual scanning is also prone to errors: items can be overlooked, scanned twice, or misread, complicating both accurate billing and inventory management.

RFID technology offers a passive, contactless alternative to barcode scanning. Each product is equipped with a cost-effective RFID tag bearing a unique identifier. This identifier is automatically read as soon as the item is placed in a corresponding shopping cart – without line of sight or manual intervention. Combined with a microcontroller, a display, and a wireless connection to a central server, the shopping cart itself becomes a point-of-sale terminal. This allows the customer to see the total amount due while shopping, and the cashier can easily retrieve the final cart contents during the checkout process.

This paper examines the current state of research on RFID-based smart shopping carts. It highlights common architectural decisions, methodological approaches, and reported results. Based on this, the design goals of a proposed ESP32-based system intended for use in supermarkets are formulated.

2. motivation

Several interacting factors motivate this study. First, the waiting time at the checkout is repeatedly cited in the literature as a major cause of customer dissatisfaction in brick-and-mortar retail, especially during peak hours. Second, the decrease in the cost of passive HF/NFC RFID tags and compact microcontrollers like the ESP32 has made automation at the shopping cart level economically viable even for medium-sized retailers. Third, rising customer expectations—driven by e-commerce and self-service technologies—have increased the demand for faster and more transparent payment processes. Finally, while existing self-checkout systems require automatic payment, they still necessitate the

manual scanning of items and are often perceived as cumbersome. Integrating RFID scanners into the shopping cart offers a solution to close this gap.

3. Literature review

Table 1 summarizes twelve representative, independently verifiable studies on RFID-based intelligent shopping cart systems published between 2014 and 2025, and describes their core methodology and key findings.

senior	Source / Year	Study title	methodology	Key finding
1	IEEE, 2014	Smart shopping cart with automatic payment system via RFID and ZigBee	RFID tag per product + ZigBee mesh communication	Establish a centralized RFID/ZigBee billing architecture early on.
2	arXiv, 2016	RFID Cloud Smart Cart System	Arduino Mega + HF RFID + OLED + Wi-Fi, cloud backend	Demonstrates the complete pipeline from shopping cart to cloud, including theft protection.
3	Procedia CS (ICCCV), 2016	Smart shopping cart with payment processing, recommendations and theft protection via RFID/ZigBee	RFID + ZigBee with theft detection logic	Adds product recommendations and theft protection to the basic billing.
4	IEEE, 2020	Supermarket shopping system with RFID as an IoT application	RFID cart with server-side synchronized inventory sensor	Improves inventory transparency and automates invoicing.
5	IEEE, 2020	Smart shopping cart based on IoT technology with RFID technology	Arduino + RFID + Bluetooth + mobile app	Mobile app integration for managing shopping lists in real time
6	IEEE, 2018	IoT applications for secure, smart shopping	RFID-based navigation and billing vehicle	Combines in-store navigation with real-time invoice calculation.
7	IEEE, 2023	Automated checkout cart for a modern supermarket with RFID technology	RFID product identification with UI feedback	The goal is to reduce waiting times and ensure correct customer billing.
8	IEEE, 2023	RFID-enabled automated billing system for retail businesses	IoT-equipped vehicle hardware	He views the overload of the checkout counters as a direct profit and loss factor.
9	IEEE, 2024	Smart shopping cart with RFID technology for greater efficiency and theft protection	NFC/RFID + PIC microcontroller + Bluetooth/ZigBee	Integrates theft prevention into product list management
10	IEEE, 2024	Revolutionizing the shopping experience with smart shopping carts	RFID + weight sensor cross-verification	Weight sensors verify RFID reads to reduce billing errors.
11	IManager Publications, 2025	RFID-enabled shopping cart with automated payment system	EM-18 RFID + Arduino, Proteus simulated design	Reports on the workflow for circuit design/calibration to ensure reliability

12	IRJET, 2019	Intelligent shopping cart system for automated payment using RFID and IoT	RFID + expiration date/weight checks + RFID at shelf level	Extend inventory monitoring to the shelves, not just the shopping cart.
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Table 1: Summary of the evaluated literature

These studies reveal three major research directions.

3.1 RFID and microcontroller integration

Most of the tested systems combine a passive RF/NFC RFID reader with an Arduino or ESP32 microcontroller mounted on or inside the vehicle. This combination allows for local processing of the tag readings and their immediate display on a connected screen, eliminating the need for a constant server connection for basic scan feedback.

3.2 Communication and Backend Architecture

A second focus is on the communication between the shopping cart and the backend systems. Approaches range from direct Wi-Fi connections to a local server and communication via smartphone app to full cloud integration with features such as personalized recommendations. Studies involving mobile applications or cloud databases generally report higher accuracy in inventory tracking, but at the cost of greater system complexity and a stronger dependence on network stability.

3.3 Billing logic and customer experience

A third aspect concerns the calculation and display of billing information. Simpler systems display a running total on an LCD screen; more advanced implementations integrate the matching of weight sensors with RFID data, shelf-level RFID systems for inventory monitoring, or anti-theft devices at the exits to speed up the payment process while simultaneously making it more secure.

A more comprehensive view at the system level is provided by current literature: An arXiv study on autonomous retail systems places RFID smart carts alongside computerized and weight-based approaches for cashierless retail and notes that RFID readers are typically positioned at the bottom of the shopping cart basket and that RSSI variance techniques are used to exclude tags outside the cart, which is directly relevant to the concerns regarding tag interference addressed in Section 5.

3.4 Publication trend

Figure 3 shows the number of studies reviewed in relation to the year of publication and illustrates a clear upward trend from 2020 onwards, as low-cost RFID modules and Wi-Fi-enabled microcontrollers became increasingly accessible for student and applied research projects.

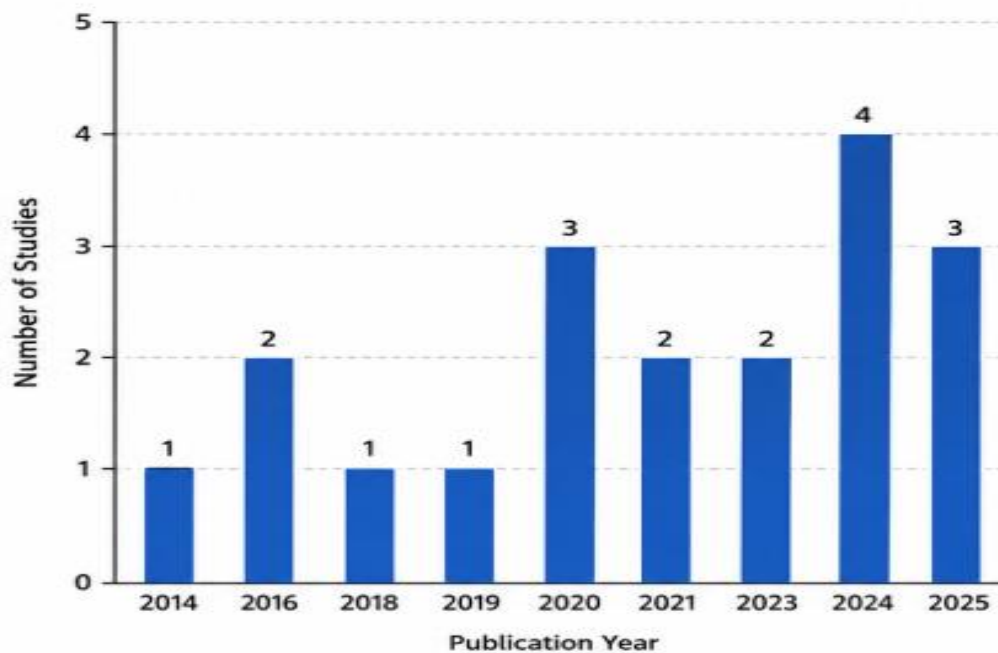


Figure 1 : Distribution of reviewed literature by year of publication (2014-2025).

3. Comparative discussion

A comparison of the examined studies reveals a uniform core architecture – RFID reader, microcontroller, display, and server connection – but also significant differences in the degree of implementation. Studies based solely on an Arduino with a small LCD (e.g., for shopping carts) demonstrate basic scanning and payment functions but report limited testing outside of controlled laboratory conditions. Systems with cloud or mobile app backends, on the other hand, offer stronger inventory synchronization and more extensive customer-oriented features, but are less rigorously tested regarding scan reliability under real-world conditions with high product density and tag interference, as is typical in a loaded shopping cart.

Few of the studies examined report on quantitative performance indicators such as scan success rates at different label densities, reductions in checkout time compared to a barcode system, or system behavior with multiple shopping carts operating simultaneously. This represents a significant research gap that every new implementation should address through structured laboratory testing and simulations in retail environments.

4. Identified research gaps

- The accuracy of the scanning can only be measured quantitatively to a limited extent if several objects equipped with RFID tags are placed close together in a single cart (tag collision/interference).
- There are few reports of real or simulated tests with multiple shopping carts and multiple customers on a retail scale.
- Inconsistent handling of latency when synchronizing inventory between shopping cart, server and store inventory records.
- Limited consideration of cost-effective, reproducible hardware bills of materials suitable for small and medium-sized retailers.
- Few studies directly compare the reduction in checkout time with a conventional barcode baseline under comparable conditions.

5. Proposed System Overview

The proposed system, based on the aforementioned gaps, integrates an RFID reader (YHY502) and a small display module with an ESP32 microcontroller, mounted on the shopping cart. Each product is equipped with a flexible 13.56

MHz NFC/HF tag (e.g., NTAG215). When items are placed in the cart, the ESP32 reads the tags, retrieves the corresponding product data, and updates the receipt in real time on the cart's display. The cart communicates via Wi-Fi with a central PC-based server, which stores product and price data and compiles the final order for each cart. Each cart is identified by a unique cart ID, allowing the cashier to retrieve and finalize the receipt without having to rescan the items.

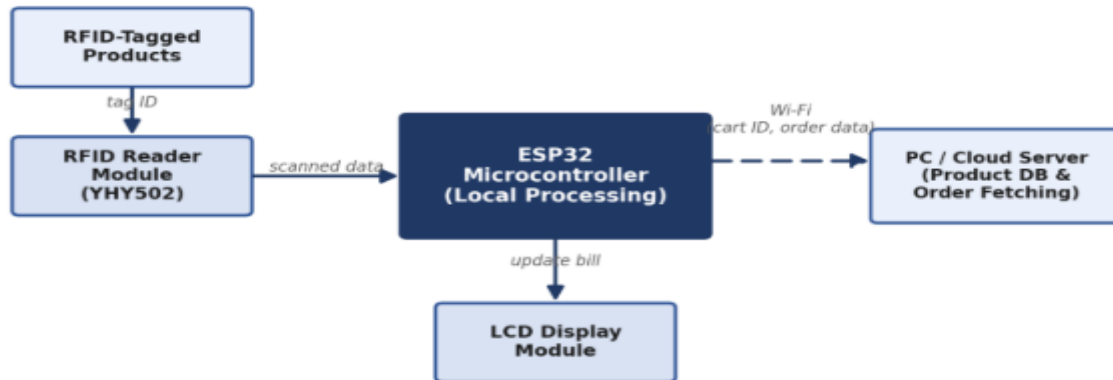


Figure 2 : Proposed system architecture showing the data flow from RFID-tagged products via the ESP32 to the display and the central server.

Figure 2 illustrates the corresponding process flow on the shopping cart page, from the time an item is placed in the shopping cart to the creation of the final invoice at the checkout.

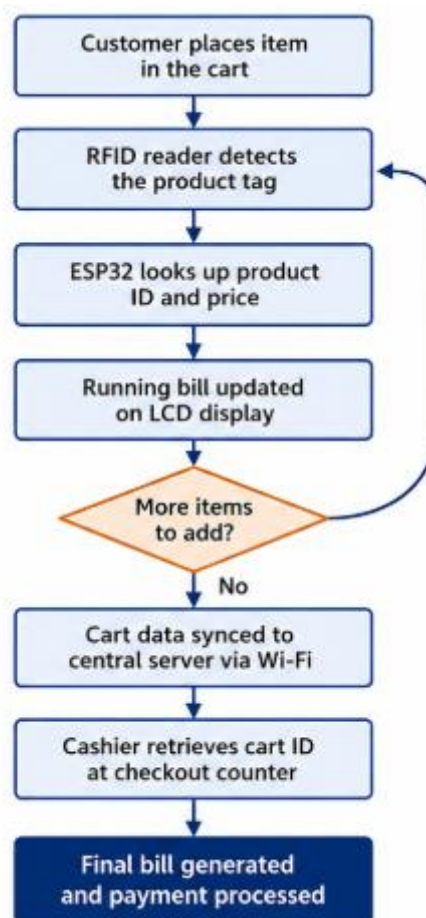


Figure 3 : Flow of the checkout process in the shopping cart, including the item-by-item scan loop and server synchronization during the payment process.

Table 2 lists the main hardware components planned for the prototype, as well as their function within the system.

Table 2: Specifications of the hardware components

<i>component</i>	<i>specification</i>	<i>Function in the system</i>
RFID tag	13.56MHz NFC/RF Adhesive Sticker (NTAG215)	Uniquely identifies each product for automatic recognition.
RFID reader	YHY502 Module	Recognizes selected products as soon as they are added to the shopping cart.
microcontroller	ESP32 (Dual-Core, Wi-Fi enabled)	It processes tag readings, controls the display, and communicates with the server.
Exhibition unit	2.4-inch SPI TFT LCD	Displays product names, prices, and the current invoice in real time.
power supply	DC power supply / rechargeable battery	Supplies power to the car's reading and control electronics.
Network interface	Integrated WLAN (ESP32)	Connects the shopping cart to the central server for data synchronization.
Central server	PC-based server with product database	Stores product/price records and generates the final shopping cart invoices.
Vehicle structure	Modified shopping cart / custom-made housing	It houses electronics and supports reliable tag scanning.

The system will be developed and evaluated in several phases: selection of components and design of the circuit diagram, construction and testing of a prototype, integration with the central server and finally testing in a simulated retail environment, followed by a performance evaluation in terms of scan accuracy, checkout speed and reliability, and the subsequent transition from the prototype to a customer-specific, printed circuit board-based implementation that will be mounted in a real shopping cart.

6. Conclusion

The reviewed literature confirms that RFID-based smart shopping carts represent a technically mature and increasingly practical approach to reducing bottlenecks at supermarket checkouts. They are characterized by a largely standardized hardware configuration consisting of an RFID reader, microcontroller, display, and server connection. At the same time, the analysis reveals significant gaps regarding quantitative performance evaluation, scalability across multiple carts, and the robustness of inventory synchronization. These gaps motivate the proposed ESP32-based smart shopping cart system. The goal is to combine the strengths of previous work—real-time transaction feedback, server-synchronized inventory, and low hardware costs—and to subject the resulting prototype to structured testing, which has only been partially addressed in the existing literature.

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