

A Survey on AI-Powered Smart Shopping Cart Systems: Integrating Barcode Scanning, Weight Validation, and Edge Computing for Automated Self-Billing

Theja K¹, Abhijith Pratheesh², Hasna Sherin A³, Fadhil Sidhick⁴

¹ Student, Dept of CSE, Sree Narayana Gurukulam College of Engineering, Kochi, India
withtheja@gmail.com

² Student, Dept of CSE, Sree Narayana Gurukulam College of Engineering, Kochi, India
abhijithpratheesh3014@gmail.com

³ Student, Dept of CSE, Sree Narayana Gurukulam College of Engineering, Kochi, India
hasnasherina835@gmail.com

⁴ Student Dept of CSE, Sree Narayana Gurukulam College of Engineering, Kochi, India
fadhilsidhick25@gmail.com

Abstract - This project presents a Smart Shopping Cart Module for Automated Self-Billing, designed to be a cost-effective, scalable retrofit unit for existing retail carts. Its primary goal is to eliminate long checkout queues and address the limitations of existing systems, such as high infrastructure costs and network dependency. The core of the system is a Raspberry Pi 4 Model B acting as the central controller, using a local SQLite database to ensure reliable offline operation for all core functions, including price lookups and billing. The system uniquely integrates camera-based product identification, utilizing a dedicated camera module for both high-speed barcode scanning and real-time object detection. A key feature is the integrated load cell sensor with an HX711 amplifier, which provides a robust theft-prevention mechanism. This security layer validates the change in physical weight against the expected product weight after scanning, enhancing security and accuracy over purely digital systems. The user interacts via an intuitive touchscreen display that shows the running total and itemized list in real time.

Key Words: Automated Self-Billing, Raspberry Pi 4 Model B, Local SQLite Database, Camera module, Load Cell Sensor, HX711 Amplifier, Weight Validation, Self-Checkout, Modular Design.

1. INTRODUCTION

The modern retail environment faces persistent challenges from long checkout queues, high operational overheads, and the risk of shrinkage in self-service concepts. Existing automated systems, particularly those relying on costly RFID or complex computer vision, are hindered by prohibitive capital costs, difficulty integrating with existing infrastructure, and critical dependency on stable network connectivity. These vulnerabilities lead to frustrated customers and increased staff intervention.

This project's motivation is to provide a cost-effective, reliable, and scalable solution. The Smart Shopping Cart Module for Automated Self-Billing overcomes these gaps by using local processing on a Raspberry Pi for offline functionality and integrating a camera-based barcode scanning with a weight-based validation mechanism to ensure product accountability and enhance security.

A. Background

The contemporary retail environment is intensely competitive and demands continuous improvements to the customer experience. Despite major technological advancements in areas like e-commerce and supply chain management, the in-store physical shopping experience is frequently hindered by a persistent issue: the checkout process. The formation of long queues at billing counters is a primary pain point for customers, often resulting in frustration, instances of cart abandonment, and overall dissatisfaction. For retailers, the traditional manual model is labor-intensive, susceptible to human error, and represents a significant operational inefficiency that negatively impacts store throughput and profitability. Existing automated solutions often present their own set of critical limitations, such as high implementation costs (e.g., universal RFID tagging), reliance on constant network connectivity, and accuracy issues with computer vision systems, which prevent their widespread adoption.

B. Problem Statement

Traditional retail checkout processes are labor-intensive, prone to delays, and negatively impact customer satisfaction. In response, there is a distinct need for a cost-effective and scalable solution that automates the billing process without requiring a complete overhaul of existing store infrastructure. Furthermore, any automated self-service solution must incorporate a robust mechanism to ensure product accountability and prevent theft, which is a critical security concern for retailers adopting self-service technologies. The ideal solution must overcome the flaws of existing advanced systems—specifically, the prohibitive cost and complexity of RFID and computer vision, and the critical dependency on stable network connectivity that plagues cloud-based IoT systems.

C. Motivation

The motivation for this project is to create a practical, reliable, and financially accessible self-billing technology that directly addresses the core inefficiencies in physical retail. By creating

a modular add-on unit that can be retrofitted onto existing shopping carts, the project eliminates the high capital expenditure associated with replacing an entire fleet of trolleys. The integration of standard barcode scanning with a sophisticated weight validation mechanism is motivated by the need for a highly accurate and secure system that operates reliably. Critically, the use of a Raspberry Pi for local processing and an onboard SQLite database is motivated by the necessity for a system that functions independently of a constant internet connection (offline capability), thereby eliminating network-dependent failures, high server maintenance costs, and data privacy risks associated with cloud solutions.

D. Objectives

1. Taxonomy and Analysis of Current Systems: Survey major smart cart architectures (RFID, Vision, Cloud IoT) to define their core mechanisms and inherent complexity.
2. Critical Examination of Limitations: Critically analyze system failures related to prohibitive costs, network dependency, and poor identification accuracy/reliability.
3. Security Mechanism Evaluation: Evaluate product accountability methods, comparing weight validation/load cells against purely vision or RFID for effective anomaly detection.
4. Synthesis of Requirements: Synthesize needs for a superior, cost-effective, modular system that guarantees offline reliability using local processing and universal identification.

2.RELATED WORKS

The technological drive toward optimizing in-store commerce has led to the development of several smart shopping cart prototypes, which can be broadly categorized by their core identification and automation strategies. A critical review of existing literature highlights the persistent challenges related to cost, operational stability, and security in these diverse systems.

A. Automatic Shopping Trolley Using IoT

This system proposed an Internet of Things (IoT) based trolley designed to expedite the billing process by utilizing RFID tags attached to products. The system relies on hardware components such as an EM-18 reader and a NodeMCU/Arduino core for data processing, enabling instant billing and supporting protocols like UPI payments. While the approach offers time savings and a simple component layout, the study revealed significant practical limitations. The system exhibited a critical dependency on a strong, persistent Wi-Fi connection, which negatively impacts its performance in expansive or crowded retail environments. Furthermore, the reliance on a central server for core functions introduces high

ongoing maintenance costs, hindering its practical scalability and cost-effectiveness.

B. Radar Self-Following Shopping Cart Based on Multi-Sensor Fusion

This system developed a sophisticated cart focused on autonomous navigation, employing a multi-sensor fusion architecture that integrates radar and computer vision. The system uses an LD-14 Radar sensor for obstacle avoidance and an onboard camera coupled with YOLOv4 and SIFT algorithms for commodity recognition. Although impressive performance metrics, such as a mean Average Precision (mAP) of 98.31%, were reported under controlled experimental conditions, the solution faces critical real-world hurdles. The high per-unit cost, driven by specialized components like the EAIDK-610 System-on-Chip (SoC) and radar, is prohibitive. More importantly, the vision-based identification is vulnerable to real-world factors like complex packaging and poor lighting, and its critical functions are dependent on a stable network connection for user authentication.

C. Smart Trolley with Automated Billing

This introduced an automated billing trolley that prioritizes a low-cost approach by utilizing a standard barcode scanner and the NodeMCU (ESP8266) processor. The system is designed to provide real-time price updates and wirelessly transmit bill information to a server, supporting faster shopping and instant payment features. Despite the cost-efficient hardware, the prototype faced significant operational challenges, including pervasive wireless communication latency and general instability. Furthermore, the security integrity was noted as a major weakness, with the documentation explicitly stating that the communication mechanism was "not entirely secure," highlighting the inherent vulnerabilities of simple, network-dependent IoT architectures lacking integrated security protocols.

D. Smart Shopping Cart with Machine Learning, Navigation, and Weighing Technologies

Detailed a comprehensive system leveraging Machine Learning (ML) for identification and integrated load cells for security. The core architecture uses a Raspberry Pi 4 to manage an ML-powered camera (utilizing models like FOMO MobileNetV2) and four integrated load cells for weighing items. A critical security protocol, termed the "Unknown Item" mechanism, automatically blocks the checkout if the load cell detects an unauthorized weight increase not correlated with an item recognized by the camera. However, the system requires a high initial investment due to the integration of advanced sensors and ML. Moreover, its reliable deployment is challenging because the weighing system exhibits high sensitivity to weight distribution and measurement variances, leading to potential operational errors that require human intervention.

Table -1: summarizes and compares the advantages and limitations of the four main shopping cart system categories reviewed in this paper.

System Type	Benefits	Limitations
Automatic Shopping Trolley Using IoT	Time savings and instant UPI payment. Simple and accessible concept for prototyping.	Critically dependent on a strong Wi-Fi connection; high server maintenance costs; poor performance in crowded retail environments.
Radar Self-Following Shopping Cart Based on Multi-Sensor Fusion	Fully autonomous shopping experience; high reported detection accuracy (mAP of 98.31%) in controlled tests.	High cost due to specialized hardware (Radar, SoC); recognition accuracy drops with complex items or poor lighting; navigation unstable in dynamic environments.
Smart Trolley with Automated Billing	Faster shopping and billing processes; real-time total cost updates; supports instant payment from the trolley.	Prototype noted as unstable; significant wireless communication latency issues; communication mechanism is "not entirely secure."
Smart Shopping Cart with Machine Learning, Navigation, and Weighing Technologies	Automatic item identification (ML/CV); integrated accurate weighing system; real-time location tracking/guidance.	High initial investment cost (ML/advanced sensors); weighing system highly sensitive to weight distribution variances; security protocol can block checkout if items are unintentionally unrecognized.

3.PROPOSED FRAMEWORK

The Proposed Framework, the Smart Shopping Cart Module, is an innovative embedded system strategically designed to circumvent the persistent issues of high cost, critical network dependency, and accuracy identified in existing retail

automation technologies. This framework introduces a pragmatic and efficient solution for automated checkout by prioritizing modularity, which enables cost-effective retrofitting onto existing shopping carts, and by ensuring core functionality remains robust through complete offline operation. The architecture integrates product identification via a reliable barcode scanner with a crucial physical weight validation mechanism, centralizing all data processing and calculation on an onboard Raspberry Pi. This integrated approach is engineered to maximize operational reliability, minimize capital expenditure, and significantly enhance inventory security.

A. Conceptual Diagram

The system's architecture is comprised of self-contained, interconnected embedded modules managed by a single high-performance edge controller, the Raspberry Pi 4 Model B. The connectivity is managed entirely onboard, eliminating reliance on a central server or store Wi-Fi for core billing functions.



Fig -1: Conceptual visualization of the Smart Shopping Cart illustrating modular components

- **Central Processing Unit:** The Raspberry Pi 4 Model B serves as the central controller, orchestrating the entire workflow and executing the custom Python application.
- **Data Acquisition Layer:** This includes the Camera Barcode Scanner, which provides reliable product identification input, and the Load Cell/HX711 Amplifier combination, responsible for precise physical weight measurement.
- **Data Core:** The Local SQLite Database stores the entire product catalog, including the expected weight metrics necessary for the security validation protocol.
- **User Interaction Layer:** The Touchscreen Display renders the Graphical User Interface (GUI), providing customers with a real-time display of their bill and accepting touch inputs for control.

B. Component Roles

The framework relies on the dedicated roles of each component to ensure seamless, secure, and independent operation:

1. Raspberry Pi 4: Functions as the embedded central controller, managing the entire workflow, executing the custom Python logic, processing inputs from peripherals, and orchestrating database queries and display updates.

2. Barcode Scanner: Serves as the reliable, primary input mechanism. It is a camera module that connects directly to the Raspberry Pi and transmits the decoded product barcode string to the application for identification and lookup.

3. Load Cell and HX711 Amplifier: This subsystem provides the physical security layer. The load cell measures the cart's total mass, while the HX711 amplifier converts the sensor's sensitive analog reading into a stable digital value for the Raspberry Pi's use in mandatory weight validation.

4. Local SQLite Database: Essential for the system's operational independence, this serverless database securely stores all critical product details - Barcode, ProductName, Price, and Expected Weight - on the device, guaranteeing that all core functions operate without external network connectivity.

5. Touchscreen Display: Offers the customer a clear, intuitive, and interactive GUI. It displays the real-time itemized bill, running total, and instructional prompts, facilitating a frictionless self-checkout experience.

6. Product Detection Camera: The Product detection camera provides an additional automated security check that detects un-scanned items or product-swapping, ensuring transaction accuracy without slowing down the customer. By running a YOLO inference model on the Raspberry Pi, the system performs real-time object classification to cross-verify that the visual identity of the product matches the scanned barcode.

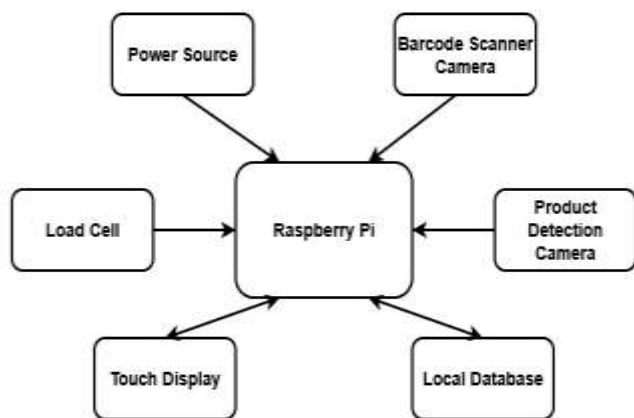


Fig - 2: Conceptual framework of a Smart Shopping Cart Module for Automated Self-Billing.

4. SECURITY AND PERFORMANCE ANALYSIS

A. Security Analysis

The proposed Smart Shopping Cart Module is engineered to provide robust security against inventory shrinkage, a critical concern often associated with self-service retail models. The system implements a dual-layer security mechanism centered

on the Weight Validation Protocol. This process provides a tangible physical verification layer designed to guarantee transaction integrity.

- **Mechanism of Dual-Layer Verification:** Upon scanning a product using the camera based barcode scanner, the system retrieves the product's pre-calibrated expected weight from the local SQLite database. The integrated load cell sensor continuously measures the actual change in weight when the customer places the item into the cart. By comparing the measured change in mass against the expected weight within a defined tolerance, the system verifies that the physically added item corresponds to the digitally scanned item.

- **Theft Prevention:** This mandatory physical security layer acts as a critical deterrent against common self-checkout fraud tactics. It specifically mitigates risks such as item swapping (where a customer scans the barcode of a lighter, cheaper product but places a heavier, more expensive item into the cart) and unscanned placement (where an item is placed without prior digital registration). This security feature is crucial for retailer confidence in deploying the self-billing technology, as it ensures that only the scanned item has been correctly added to the cart.

B. Performance Metrics

The architectural choices of the modular framework are specifically optimized for high performance, reliability, and cost efficiency, directly addressing the limitations of complexity and network dependency identified in existing literature.

- **Operational Reliability and Connectivity Independence:** A cornerstone of the system's performance is its connectivity independence. By utilizing a high-performance Raspberry Pi 4 Model B and storing all critical product data (price, expected weight) in a Local SQLite Database, the core functions—scanning, price lookups, and security validation—are executed entirely offline. This design choice drastically enhances operational reliability by eliminating potential system failures caused by network instability or intermittent Wi-Fi connectivity in large retail environments.

- **Efficiency and Speed:** The system is designed to maximize store throughput and customer satisfaction. By enabling customers to scan and bill items as they shop, the solution completely eliminates time spent waiting in traditional checkout queues. The real-time billing update displayed on the touchscreen provides immediate feedback, contributing to a seamless and efficient self-checkout experience.

- **Cost-Effectiveness and Scalability:** The modular nature of the design positions it as a cost-effective and scalable innovation. By acting as an add-on unit that can be retrofitted onto existing shopping carts, the system avoids the massive capital expenditure (CAPEX) associated with replacing entire

cart fleets or installing expensive, proprietary infrastructure like universal RFID tags. This results in a lower Total Cost of Ownership (TCO) for retailers compared to high-end vision-based or complex cloud-dependent systems.

5. FUTURE SCOPE

Building upon its robust, modular foundation, the proposed system is well-positioned for several advanced future enhancements. A critical next step involves integrating seamless payment solutions, potentially including NFC readers for contactless card and digital wallet payments, or QR code systems, to ensure a complete end-to-end shopping and checkout experience entirely contained within the cart. To further enhance customer engagement and sales, the system can be upgraded with AI-Powered Recommendations that analyze real-time shopping patterns to deliver personalized product suggestions directly on the touchscreen. Operational efficiency can be boosted through Real-Time Inventory Management functionality, allowing the cart to update the store's stock levels via a local network API as items are purchased. Furthermore, future development could explore features like Augmented Reality (AR) Engagement—using a camera to overlay information or guidance on the display—and incorporate sustainability features such as energy harvesting systems to reduce reliance on external power and minimize environmental impact.

6. CONCLUSION

The "Smart Shopping Cart Module for Automated Self-Billing" represents a significant and practical advancement designed to tackle the critical retail pain point of protracted billing queues and corresponding operational inefficiency. By developing a solution that is modular, cost-effective, and fully offline-capable, this project effectively resolves the major drawbacks—namely critical network dependency and high infrastructure investment—that have historically impeded the widespread adoption of previous smart cart technologies. The system's foundational architecture, centered on a Raspberry Pi for local data processing, integrates a reliable barcode scanner with a mandatory weight validation mechanism. This combined approach establishes a highly secure and accurate self-checkout experience, successfully guaranteeing transaction integrity and significantly mitigating potential inventory loss for the retailer, all while providing a seamless, efficient journey for the customer.

REFERENCES

- [1] T. Raj, Y. Cheema, V. K. Singh, A. Kumar, and S. N. Gupta, "Automatic shopping trolley using IOT," ELSEVIER, 2022. Doi : 10.1016/j.matpr.2022.12.152
- [2] L. Yao, T. Li, R. Tong, K. Wang, and L. Zhang, "Radar Self-Following Shopping Cart Based on Multi-Sensor Fusion," IEEE Access, 2023. Doi : 10.1109/ACCESS.2023.3297889
- [3] M. I. Zulfikar, A. Khalid, A. Siddig, M. J. Nawaz, and S. Saay, "AI-Driven Smart Shopping Carts With Real-Time Tracking and Inventory Forecasting for Enhanced Retail Efficiency," IEEE Access, 2025. Doi : 10.1109/ACCESS.2025.3553854
- [4] M. A. A. Roslan and H. Haron, "Designing the Smart Shopping Cart Mobile Application (SmartCart) Using Mobile Application Development Life Cycle," Modern Education and Computer Science Press, 2024. Doi : 10.5815/ijitcs.2024.04.05
- [5] S. Wakode, P. Arakhras, A. Dive, and K. Bandal, "Smart Trolley with Automated Billing," International Research Journal of Engineering and Technology (IRJET), 2022.
- [6] A. A. Aldawood, S. A. Alhuwaidi, and A. A. Hussain, "Smart Shopping Cart With Machine Learning, Navigation, and Weighing Technologies," IEEE Xplore, 2024. Doi : 10.1109/ISAECT64333.2024.10799859
- [7] S. V, G. D, P. S, and S. S, "An Automated Billing System for Smart Shopping Using Internet of Things," International Research Journal On Advanced Engineering Hub (IRAJAEH), 2024. Doi : 10.47392/IRJAEH.2024.0137
- [8] M. Mhetre, T. Uge, S. Shewade, A. Patil, and K. Markad, "Development of a Smart Shopping Cart for Enhanced Retail Experience," International Journal For Research In Applied Science & Engineering Technology (IJRASET), 2024.
- [9] O. Dhaneesha, B. Pranusha, B. Madhavi, and C. Greeshma, "Automation Of Shopping Cart Using Raspberry Pi," International Research Journal of Engineering and Technology (IRJET), 2022.
- [10] X. Liang, Y. Qi, S. Xi, G. Meng, and Z. Wang, "Design and development of full self-service smart shopping system for unmanned supermarket," SPRINGER, 2025.