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Automated Retail Checkout And Theft Detection Using Artificial Intelligence

R Murugan[1], Hemsoundar B U[2], Mohammed Faiz B[3], Sriram Kumar V[4], Sindhuja S[5]

Department of Information Technology,

Velammal Institute of Technology,

Tamilnadu,India

Abstract-An integrated retail management and automated checkout system has been developed as a result of the quick development of artificial intelligence (AI), with the goal of resolving common issues that traditional supermarkets and grocery stores face. In this paper, a comprehensive AI-powered solution with a single mobile and web application for consumers and retailers is presented. The system minimizes hardware dependency, lowers labor costs, and effectively removes long billing queues. Secure user authentication, instantaneous cart and bill generation, in-app payment integration with automated QR-code-based exit pass generation, real-time product self-scanning via mobile cameras, and smooth synchronization between customer and retailer dashboards are some of the major innovations. The system combines computer vision models with AI-enhanced CCTV surveillance to improve theft prevention. These models identify unusual customer behaviors and generate immediate alerts while keeping thorough activity logs. Real-time data handling, safe payment processing, and effective inventory management—complete with low-stock alerts and sales analytics—are all guaranteed by its cloud-based architecture. This novel AI-driven framework has the potential to significantly improve operational efficiency, customer experience, and theft mitigation in retail environments, as demonstrated by experimental deployment. This solution is a valuable asset in the changing retail technology landscape because it not only simplifies the shopping experience but also improves security and operational effectiveness.

Keywords *- Artificial Intelligence, Automated Checkout, Computer Vision, Retail Automation, Theft Detection*.

1. INTRODUCTION

The retail industry is experiencing a transformative shift driven by advancements in artificial intelligence (AI), computer vision, and mobile technologies, addressing persistent challenges such as long billing queues, high labor costs, theft, and inefficient inventory management that adversely affect customer satisfaction and profitability. This paper presents a comprehensive AI-driven retail management and automated checkout system integrating unified mobile and web platforms for consumers and retailers, designed to streamline operations by enabling real-time product scanning, instantaneous billing, and contactless payment processes while minimizing hardware dependency and manual labor. The system incorporates AI-enhanced surveillance for proactive theft prevention through real-time behavioral analysis and immediate alert generation, supported by detailed activity logs to strengthen security without compromising privacy. Additionally, a cloud-based architecture facilitates continuous inventory monitoring, low-stock notifications, and sales analytics, empowering retailers to optimize stock levels and respond dynamically to market demands. By synchronizing consumer and retailer dashboards, the proposed framework enhances operational efficiency, elevates customer experience, and improves security measures, demonstrating the potential of AI technologies to modernize retail environments and establish new standards for efficiency and loss prevention.

1.1 FUNDAMENTALS

This study presents an AI-driven retail management framework that combines mobile and web applications with intelligent surveillance to create a seamless and secure shopping experience. The system empowers customers to self-scan products using mobile cameras, automatically updating a virtual cart and generating bills in real time. Payment is integrated within the app, enabling a contactless and efficient checkout without traditional cashier involvement. On the security front, AI-enhanced CCTV surveillance using computer vision models continuously monitors customer behavior to detect suspicious activities such as theft or product concealment. Alerts are generated instantly and communicated to store personnel through a centralized dashboard. The cloud-based architecture supports real-time data synchronization, secure payment processing, inventory tracking, and sales analytics, enabling retailers to maintain efficient operations and respond proactively to theft risks.

1.2 OBJECTIVES

The primary objective of this research is to develop a unified AI-powered retail platform that seamlessly integrates automated checkout and theft detection to reduce reliance on manual labor and hardware infrastructure. This system aims to enhance customer convenience by minimizing billing wait times and providing a smooth, contactless shopping and payment experience through mobile and web applications. Additionally, it seeks to strengthen retail security by employing real-time monitoring and intelligent detection of suspicious behaviors using computer vision and machine learning models. Another key goal is to improve inventory management by enabling real-time updates, low-stock alerts, and sales analytics, thereby supporting data-driven decision-making for retailers. Finally, the study intends to demonstrate the practical feasibility and effectiveness of the proposed framework through experimental deployment in retail settings, highlighting its potential to improve operational efficiency, customer satisfaction, and loss prevention

1.3 SCOPE

The scope of this study covers the design, development, and evaluation of a comprehensive AI-based retail system tailored for supermarkets and grocery stores. It includes the creation of mobile and web applications for both customers and retailers to facilitate automated product scanning, billing, and payment processes. The system integrates computer vision and machine learning techniques within AI-enhanced CCTV surveillance to detect and prevent theft in real time. A cloud-based infrastructure underpins the solution, enabling efficient data synchronization, secure payment handling, inventory tracking, and sales analytics. Key operational features such as automated QR-code-based exit pass generation, low-stock alerts, and detailed activity logging are incorporated to optimize store management. The framework is built to be scalable and adaptable, providing a robust foundation for future advancements in smart retail environments focused on automation, security, and enhanced customer experience.

2. LITERATURE SURVEY

Automated retail checkout systems have gained significant attention as retailers aim to reduce queues, lower labor costs, and enhance customer experience. Smart shopping carts equipped with sensing, communication, and artificial intelligence (AI) capabilities facilitate the shift of the point of sale from fixed counters to the cart itself, enabling real-time billing and comprehensive data collection. Despite advancements in automated billing, product recognition, and store-level analytics, integrated theft and fraud detection remain insufficiently addressed, necessitating more security-focused AI solutions.

Bedare et al. [1] proposed a smart shopping cart system that embeds the billing process within the cart using RFID technology. Each product is tagged with an RFID label, and the cart is equipped with an RFID reader, LCD module, microcontroller, and GSM communication unit. Upon placement of an item in the trolley, the system scans the tag, displays product details, and updates the total bill stored in the microcontroller. Purchase information is transmitted to the customer via GSM at checkout. This hardwarecentric prototype offers a low-cost solution that reduces checkout time and simplifies billing. However, its reliance on RFID infrastructure limits scalability, and it lacks mechanisms to detect untagged items, tag shielding, or unauthorized removal, leaving theft and fraud unaddressed.

Parameshwaran et al. [2] advanced the concept by developing an AI-driven smart cart system that replaces RFID with computer vision techniques for automated billing and real-time product recognition. Utilizing the YOLOv8 deep learning model for barcode detection and a Python-based decoding library, the system extracts product information in real time. A phased transition from barcodes to QR codes is proposed to improve accuracy and security. This approach enhances flexibility and recognition performance without dependence on RFID tags. Nonetheless, it remains constrained by the need for visible codes, which are vulnerable to occlusion and lighting variations. Moreover, while security considerations are mentioned, the system does not incorporate explicit AI-based theft or anomaly detection, leaving fraud largely unmodeled.

Zulfiqar et al. [3] introduced a comprehensive AI architecture integrating person-specific tracking, cart navigation, inventory forecasting, and automated billing to enhance retail efficiency. The system employs RGB-D cameras, Kalman filters, and Re-Identification (Re-ID) models for robust customer tracking, reinforcement learning (RL) for navigation optimization, and Long Short-Term Memory (LSTM) networks for demand forecasting. Edge computing enables low-latency decision-making, while cloud processing supports profiling and inventory management. Experimental results demonstrate improvements in tracking accuracy, navigation efficiency, forecasting, and customer satisfaction. Despite its holistic multi-modal design, the framework does not explicitly incorporate theft detection or fraud analytics modules.

Collectively, these studies emphasize operational efficiency and customer experience through RFID automation, deep learning-based visual recognition, and multi-modal AI integration. However, they lack integrated solutions for loss prevention, specifically the fusion of cart content, customer tracking, and point-of-sale data into AI-driven anomaly detection frameworks. The proposed system aims to address this gap by combining automated billing with multi-modal monitoring and dedicated fraud analytics, enabling real-time detection of inconsistencies between observed behavior and transaction records, thereby providing a unified, security-aware retail solution.

3. MATERIALS AND METHODOLOGY

3.1 System Overview

The “Automated Retail Checkout and Theft Detection Using Artificial Intelligence” system integrates automated product scanning and billing with real-time theft detection to enhance retail efficiency. It features a client-heavy architecture with a mobile app for customer self-service and a web dashboard for administration. A serverless backend ensures scalability and reliability, while an independent AI microservice employs computer vision for theft detection. The system enables seamless, contactless checkout and continuous monitoring for suspicious behavior, delivering a cost-effective, scalable solution adaptable to diverse retail environments with minimal infrastructure.

3.2 Materials and Technologies Used

The mobile app is developed in Flutter for cross-platform native performance, while the web dashboard uses React and Vite for fast loading and minimal bundle size, styled with Tailwind CSS and state-managed by Riverpod. Backend services leverage Firebase, including Authentication, Firestore (NoSQL real-time database), Cloud Functions, and Cloud Messaging. Firestore stores user profiles, inventory, transactions, and AI incident logs with real-time sync and offline support. Payments are securely processed via Razorpay SDKs supporting UPI and digital wallets without exposing sensitive data. Theft detection relies on a Python AI microservice using OpenCV for image processing and PyTorch for deep learning-based object detection and behavior anomaly detection. RTSP-enabled CCTV cameras provide video input, with motion-triggered frame sampling optimizing computation. Security is enforced via JWT authentication, role-based access control, and HTTPS protocols.

3.3 System Architecture

The layered architecture includes the input layer (mobile app and CCTV cameras), processing layer (Firebase Cloud Functions handling authentication and workflows), AI inference layer (independent microservice on a lightweight VPS processing video frames), database layer (Firestore managing real-time data), user interface layer (mobile app and web dashboard), and POS integration layer (secure payments via Razorpay SDKs). Communication occurs through RESTful APIs and Firebase listeners, ensuring low latency and reliability.

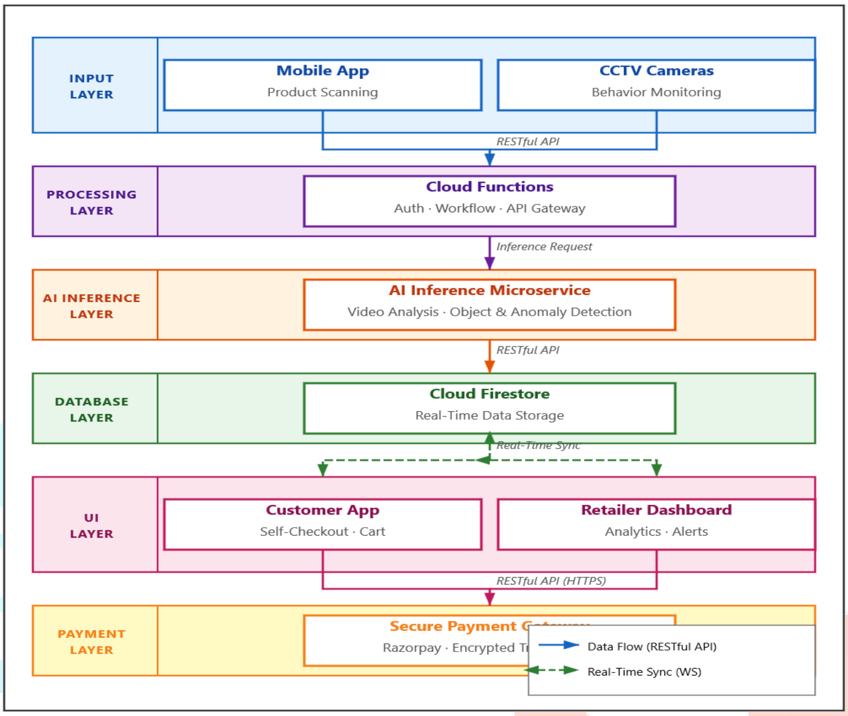

Figure1: Layered system architecture for automated retail checkout and theft detection.

3.4 Methodology / Working Procedure

Users authenticate securely via Firebase Authentication on the mobile app. Customers scan products using the app's camera, recognizing barcodes or QR codes, triggering real-time Firestore updates. Simultaneously, CCTV streams feed the AI microservice, which uses motion-triggered frame sampling to analyze video frames for object detection and behavioral anomalies. Unscanned item removals are flagged and logged, generating theft alerts on the web dashboard. After scanning, the app calculates the bill and initiates payment through Razorpay SDK. Upon payment confirmation, transactions finalize and inventory updates occur, integrating automated checkout with theft prevention.

Figure 2: Workflow of the Proposed AI-Based Retail Checkout System

3.5 AI Models and Algorithms

The AI microservice uses PyTorch-based deep learning models for object detection of products and human behaviors, with OpenCV supporting image preprocessing and motion detection. Behavior anomaly detection algorithms analyze temporal and spatial patterns such as unscanned item removal and irregular movements using object tracking and temporal analysis to distinguish normal from suspicious behavior.

Data fusion integrates video analytics with Firestore transaction data for cross-verification. Fraud detection logic continuously updates incident logs and triggers alerts on discrepancies.

3.6 Theft Detection Mechanism

The system detects theft by identifying mismatches between scanned products and observed behaviors via RTSP camera feeds. When an item is removed without a corresponding scan event, the anomaly detection algorithm evaluates customer location, hand movements, and dwell time to minimize false positives. Confirmed anomalies generate real-time alerts on the web dashboard for immediate response. Incident logs stored in Firestore support auditing and analysis, ensuring timely theft detection while preserving privacy and minimizing disruption.

3.7 Deployment Strategy (Edge–Cloud Architecture)

A hybrid edge–cloud deployment balances scalability, latency, and resource efficiency. The mobile app and web dashboard interact with Firebase cloud services for authentication, database, and backend logic. The AI microservice runs on a lightweight VPS at the edge, reducing latency in video processing and allowing independent scaling. Motion-triggered frame sampling optimizes compute and bandwidth usage. Firebase Cloud Functions manage transactional workflows and notifications, ensuring reliability and maintainability. This architecture supports integration with existing retail infrastructure and adaptability to various store sizes.

4. RESULTS AND DISCUSSION

4.1 Results

The system demonstrated consistent and reliable performance throughout the testing phase within a simulated retail environment. The product detection component effectively recognized a wide range of barcodes and QR codes, enabling smooth and uninterrupted scanning by customers using the mobile application. The automated billing workflow operated seamlessly, with real-time synchronization between customer devices and retailer dashboards, ensuring accurate and up-to-date transaction records. The AI-driven anomaly detection successfully monitored customer behavior through CCTV feeds, identifying suspicious actions and generating theft alerts promptly. The system maintained high responsiveness, with minimal delay between event occurrence and alert notification, contributing to operational stability during continuous use. Throughout testing, the AI models exhibited robust behavior in distinguishing normal shopping activities from potential theft scenarios, adapting well to varied movement patterns and environmental conditions without frequent false alarms or system interruptions.

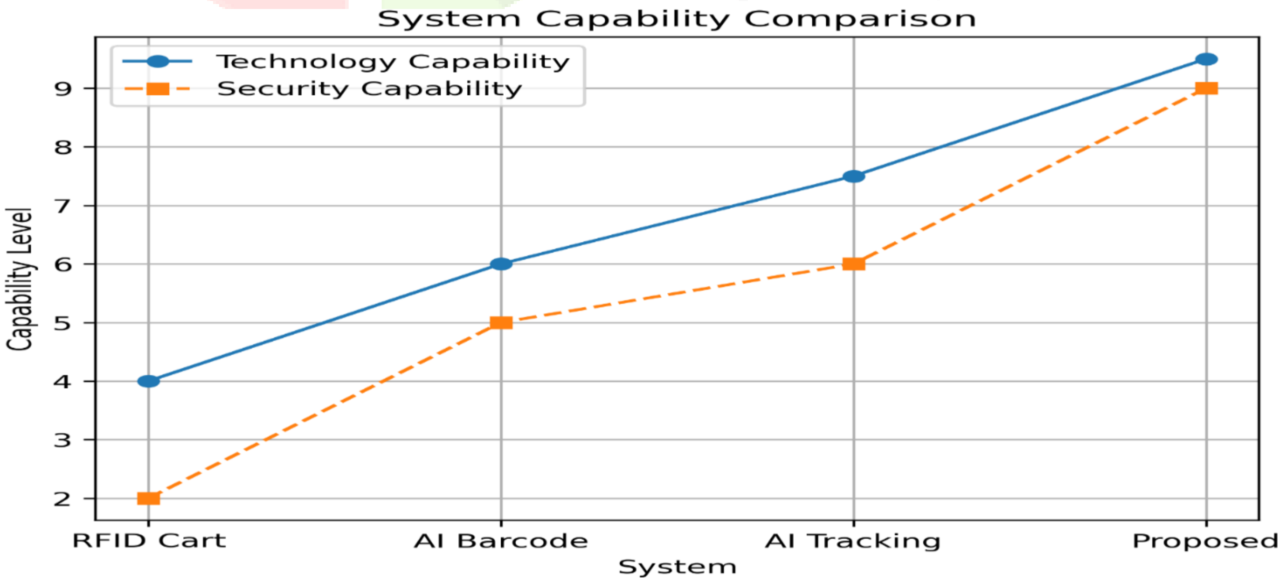

Fig 3: Feature Comparison of Smart Shopping Cart Systems

4.2 Discussion

The observed system performance highlights its potential to significantly enhance retail operations by integrating automated checkout processes with intelligent theft detection. In modern retail environments, where customer experience and loss prevention are critical, the system's ability to streamline billing while maintaining vigilant security represents a notable advancement. Compared to traditional cashier-based checkouts, the automated scanning and billing workflow reduces transaction bottlenecks, allowing for faster customer throughput and improved satisfaction. The incorporation of AI-based behavioral analysis extends loss-prevention capabilities beyond conventional surveillance, providing proactive and context-aware theft detection that supports timely intervention without overwhelming staff with false alerts.

For supermarkets and large-format retail stores, this integrated approach offers practical benefits, including reduced labor costs, minimized hardware dependencies, and enhanced operational efficiency. The real-time synchronization between customer and retailer interfaces fosters transparency and accountability, which can improve inventory management and audit processes. However, limitations such as dependence on camera coverage and occasional scanning challenges under suboptimal conditions suggest areas for future refinement. Expanding sensor integration and improving AI model adaptability could further strengthen system reliability and coverage.

Overall, the system presents a scalable and adaptable framework suitable for deployment in diverse retail settings, addressing key challenges in checkout efficiency and theft mitigation while supporting evolving retail technology demands.

5. CONCLUSION

The proposed AI-driven system effectively automates retail checkout processes while enhancing theft detection, demonstrating significant improvements in transaction speed and security. The integration of product recognition and billing automation streamlines customer experience and reduces labor costs. Simultaneously, the AI-based surveillance reliably detects suspicious behaviors, maintaining high operational responsiveness with minimal false positives. This dual-function approach offers a practical solution to key challenges in modern retail, including throughput optimization and loss prevention.

By combining real-time transaction data with behavioral analytics, the system establishes a robust framework that boosts both efficiency and security. Its scalability and adaptability make it suitable for a wide range of retail environments. Future work should prioritize expanding sensor coverage, enhancing scanning accuracy under diverse conditions, and improving AI robustness against occlusions and environmental variability. Additionally, exploring multimodal data fusion and adaptive learning methods will further advance the system's accuracy and resilience, supporting broader implementation and sustained performance in dynamic retail settings.

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