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An Automated Smart E-Cart System for Real-Time Billing and Inventory Control

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Abstract: Conventional retail checkout systems depend on cashier-operated billing counters, which often cause delays, overcrowding, and inefficient stock management. With increasing customer volume, these systems become time-consuming and prone to manual errors. This
paper introduces an automated Smart E-Cart system that integrates product scanning, billing computation, secure digital payment, and inventory tracking into a single platform. By enabling customers to manage purchases independently, the system minimizes checkout time and improves operational efficiency. The proposed solution leverages web-based technologies and a centralized backend to deliver a fast, reliable, and user-centric shopping experience, making it suitable for modern smart retail environments.
Keywords: Smart E-Cart, Automated Billing, Barcode Technology, Inventory Control, Spring Boot, Online Payment

I. INTRODUCTION

Retail shopping environments such as supermarkets and shopping malls are experiencing rapid growth due to increasing urbanization and consumer demand. However, traditional checkout systems used in most retail stores still rely heavily on cashier-operated billing counters. In such systems, customers must wait in long queues while each product is manually scanned and billed by a cashier. This process becomes inefficient during peak hours when large numbers of customers are present, leading to overcrowding, increased waiting time, and reduced customer satisfaction.Inaddition to long waiting times, traditional billing systems are also prone to human errors such as incorrect product entry, billing mistakes, and inaccurate inventory updates. These issues not only affect customer experience but also impact the operational efficiency of retail businesses. Therefore, the development of automated billing systems has become an important research area in modern retail technology.Recentadvancements inweb technologies, computer vision, and automated barcode scanning systems have enabled the development of intelligent retail solutions that improve shopping efficiency and reduce dependency on manual billing processes. Smart shopping systems allow customers to scan products while shopping, automatically calculate the total bill, and complete payment digitally without waiting at checkout counters [1], [4].Barcodetechnology has become one of the most widely used methods for product identification in retail environments. Each product contains a unique barcode that stores information such as product ID, price, and category. By scanning the barcode using a camera-based system, product information can be retrieved instantly from the database. Modern JavaScript libraries such as Quagga2 allow real-time barcode scanning directly through web browsers using device cameras, making it possible to build cost-effective automated billing systems without requiring specialized hardware.Severalresearch studies have explored automated shopping systems using different technologies to improve retail automation. Smart shopping cart systems and automated billing platforms have demonstrated the potential to reduce checkout time and improve operational efficiency in retail stores [5], [16]. However, many of these systems require complex hardware setups or specialized equipment, which increases implementation costs.Toovercome these limitations, this research proposes a Smart E-Cart system that uses JavaScript-based barcode scanning with the Quagga2 library, a Spring Boot backend server, andacentralized product database to create a fully automated shopping experience. Customers can scan product barcodes using their mobile device or kiosk camera, add items to their digital cart, and view the total bill in real time.Thesystem automatically retrieves product information from the backend database, calculates the total price, and allows customers to complete transactions through secure online payment systems. Additionally, the system updates inventory data after each purchase, enabling efficient stock management for store administrators.Theproposed Smart E-Cart system aims to reduce checkout time, minimize human errors, and provide a seamless shopping experience.

By integrating barcode scanning, automated billing, and digital payment processing into a single web-based platform, the system provides an affordable and scalable solution suitable for modern smart retail environments.

II. LITERATURE SURVEY

Automated retail systems have been widely studied in recent years due to the growing demand for efficient shopping experiences and improved retail management. Researchers have proposed various smart shopping solutions that aim to automate the billing process and reduce customer waiting time.Shahrozet al. presented an IoT-based smart shopping system designed to automate the retail checkout process using wireless communication technologies and automated product detection mechanisms [1]. Their research demonstrated that automated billing systems can significantly improve retail efficiency and reduce manual intervention.

Suganya et al. developed an automated smart trolley system that allows products to be scanned automatically and billed without requiring a cashier [2]. Their work emphasized the importance of integrating automation technologies into retail stores to reduce billing delays.Another study introduced the Cart automated billing system, which enables customers to scan products and generate bills automatically during the shopping process [3]. This approach highlighted the potential for digital billing systems to improve shopping convenience.Gangwal et al. proposed a smart shopping cart system that uses wireless communication networks to automate product billing and inventory tracking [4]. Their study showed that integrating smart technologies in shopping carts could improve the efficiency of retail management systems.Research conducted by Sainath et al. introduced an automated shopping trolley system that eliminates the need for traditional checkout counters by allowing customers to manage their purchases directly through the shopping cart interface [5].More recent studies have focused on integrating mobile computing and cloud-based technologies into smart retail systems. Sarwar et al. proposed a mobile-enabled smart shopping system that combines cloud computing and intelligent data processing to provide enhanced retail automation [16].Additionally, Li et al. discussed secure IoT-based shopping systems that provide efficient communication between retail devices and centralized servers to ensure reliable data processing and billing operations [18].Although these systems provide significant improvements in retail automation, many of them rely on specialized hardware components or complex infrastructure, which can increase deployment costs. In contrast, barcode-based systems combined with modern web technologies provide a simpler and more cost-effective solution for automated billing.Theproposed Smart E-Cart system addresses these challenges by using JavaScript-based barcode scanning with the Quagga2 library, which allows real-time barcode detection using standard device cameras. This approach eliminates the need for specialized scanning devices while maintaining accurate product identification and efficient billing operations.

III. RELATED WORK

A. Barcode-Based Product Identification

Barcode technology is one of the most widely used product identification methods in retail systems. A barcode is a machine-readable code that stores product information in the form of parallel lines and spaces. When scanned using a barcode scanner or camera-based system, the encoded information is decoded and used to retrieve product details from a database [1], [9]. Barcode-based systems are highly reliable and cost-effective compared to other identification technologies. Modern computer vision libraries allow barcode detection through standard cameras, enabling the development of web-based scanning applications [16].

B. JavaScript-Based Barcode Scanning

With the advancement of web technologies, barcode scanning can now be performed directly within web browsers using JavaScript libraries. One such library is Quagga2, which is an open-source JavaScript library designed for real-time barcode detection using computer vision techniques.Quagga2 processes video streams from device cameras and identifies barcode patterns using image processing algorithms. Once the barcode is detected, the decoded product ID is sent to the backend server where product details are retrieved from the database [4], [18]. This approach allows users to scan products using smartphones, tablets, or web kiosks without requiring external scanning hardware.

C. Smart Retail Web Applications

Modern retail systems are increasingly adopting web-based platforms for managing billing, inventory, and customer interactions. Web applications provide flexibility, scalability, and cross-device compatibility, allowing customers to access services through mobile phones, tablets, or computers [7], [10].By combining barcode scanning, automated billing, and digital payment integration within a web-based system, smart retail platforms can significantly enhance the efficiency of shopping operations [14], [20].

IV. RESEARCH METHODOLOGY

The development of the Smart E-Cart system followed a rigorous, multi-phase engineering methodology. This structured approach ensured that the software architecture was scalable, the data flow was secure, and the user interface met modern usability standards [1], [16].

1) Phase I: System Requirement Analysis and Database Schema Design

The initial phase involved identifying the core functional requirements of a frictionless retail environment. A Centralized Product Repository was architected to serve as the "Source of Truth" for the application [18].

Data Modeling: We designed a relational schema to store critical attributes, including unique Global Trade Item Numbers (GTIN) for barcodes, localized product naming conventions, real-time pricing, and atomic stock quantities [9].

Normalization: The database was normalized to ensure that inventory updates and transaction logs remained consistent, preventing data redundancy [20].

2) Phase II: Frontend Architecture and Vision Integration The user-facing component was developed as a responsive Single Page Application (SPA) using a stack of HTML5, CSS3, and modern JavaScript [13].

Real-Time Scanning Engine: A critical technical milestone was the integration of the Quagga2 library. This involved configuring the MediaDevices API to access the high-resolution hardware of mobile device cameras [16].

Stream Processing: We implemented an image processing pipeline that captures raw video frames, applies binarization and localization filters, and extracts the barcode string directly within the browser's execution context.

3) Phase III: Backend Orchestration and RESTful Integration The middleware was engineered using the Spring Boot framework to handle the business logic and secure data routing [17].

Request-Response Cycle: When a barcode is decoded by the client, a RESTful POST request is dispatched to the backend. The server intercepts this request, executes a prioritized query against the database, and returns a JSON payload containing the product's metadata [4].

Dynamic Cart Management: The system logic is programmed to handle state changes instantaneously. As items are added or removed, the backend recalculates the subtotal, taxes, and final bill, pushing these updates back to the frontend to ensure the user has real-time financial visibility [5], [14].

4) Phase IV: Transactional Security and Inventory Reconciliation The final phase focused on the "Check-out" flow and system integrity [17].

Payment Gateway Integration: We implemented a secure handshake with an online payment API. This ensures that the transaction is processed over encrypted channels, protecting user financial data [7].

Inventory Synchronization: To maintain accurate stock levels, we developed a Post-Payment Webhook. Only upon receiving a "Transaction Success" confirmation does the system trigger an automated SQL update to decrement the purchased quantities in the database. This prevents "Inventory Leakage" where items are scanned but not paid for [1], [20].

5) Phase V: Performance Evaluation and System Tuning Post-development, the system underwent a Validation Phase. We conducted stress tests to measure the latency of the barcode-to-database round trip and verified the accuracy of the automated billing calculations [8]. This iterative feedback loop allowed us to fine-tune the Quagga2 detection parameters and optimize backend query performance for a production-ready state [10]

V. PROPOSED SMART E-CART SYSTEM

The proposed system shifts the retail paradigm from a labor-intensive, centralized model to a decentralized, automated framework [1], [5]. Unlike traditional systems that require physical movement of goods through a single checkpoint, the Smart E-Cart virtualizes the Point-of-Sale (PoS) directly onto the consumer's mobile device or an integrated tablet on the trolley [16].

A. Functional Overview

The core objective of the proposed solution is to eliminate the linear bottleneck of manual scanning. The system is designed to handle three critical retail operations simultaneously:

- Edge-Based Identification: Using the Quagga2 engine, the system processes visual data at the "edge" (the user's device), reducing server load and ensuring immediate feedback [16].

- Synchronous Cart Management: The system maintains a persistent digital state for each user. Every time a barcode is successfully parsed, the frontend communicates with the Spring Boot backend to fetch real-time pricing, ensuring that the user's "Running Total" is always accurate [4], [14].
- Automated Inventory Reconciliation: The system introduces an automated trigger mechanism. Upon payment confirmation, the database executes an atomic transaction to update stock levels, effectively merging the sales and inventory management processes into a single event [17], [20].

B. Key Features of the Proposed Framework

To ensure the system is "Smart" and not just a digital list, the following advanced features were implemented:

- Dynamic Item Modification: Users have the autonomy to add or remove quantities of items directly from the interface. The backend logic ensures that the subtotal and tax calculations are recomputed instantly without requiring a page refresh [13].
- Universal Barcode Support: The scanning module is configured to recognize multiple formats, including EAN-13, UPC-A, and Code 128, making it compatible with a wide variety of global consumer goods [9].
- Dual-Mode Payment Verification: Recognizing the diverse nature of retail transactions, the system supports both automated digital payment (via API) and an "Admin-Verified Cash Request" for users who prefer traditional currency, ensuring 100% inclusivity [7], [18].
- Digital Receipting: Upon the successful closing of a transaction, the system generates a unique, timestamped digital invoice. This receipt is both displayed on the UI and dispatched to the user's registered email, providing a paperless audit trail [10].

C. Advantages Over Conventional Systems

The proposed system offers several strategic advantages:

- Reduced Overhead: Retailers can operate with fewer billing staff, reallocating human resources to customer service and floor management [1], [8].
- Data-Driven Insights: By capturing every item scanned in real-time, the system provides administrators with a granular view of "Live Sales" and "Stock Velocity" [4].
- Enhanced Consumer Autonomy: By providing a transparent view of the total bill throughout the shopping journey, the system helps consumers manage their budgets effectively before reaching the exit [10], [16].

VI. SYSTEM ARCHITECTURE

The proposed Smart E-Cart system is designed using a layered architecture that integrates barcode scanning, web technologies, backend processing, and database management to enable automated shopping and billing. The system architecture is divided into three major layers: User/Client Layer, Application Layer, and Database Layer, as illustrated in Fig. 1.

A. User / Client Layer

This layer serves as the primary touchpoint for the consumer, developed as a responsive web interface.

- Scanning & Identification: Implements the Quagga2 library to utilize device camera hardware for real-time barcode decoding.
- Cart Management: Features a dynamic UI that updates the product list and total expenditure in real-time via state management.
- Transaction Workflow: Facilitates two payment modes: Digital Payment (via secure Gateway API) and Cash Payment Request (forwarded for Admin approval).
- Finalization: Post-verification, this layer captures customer metadata to generate and deliver invoices via automated email or thermal printing.

B. Application Layer

Acting as the core processing engine, this layer manages business logic and cross-tier communication.

- Backend Orchestration: Developed using Spring Boot, it handles RESTful API requests for product lookups and transaction processing.
- Administrative Interface: A dedicated module for store managers to perform CRUD operations on the product database, monitor transaction histories, and validate pending cash payments.

- Validation Logic: Manages the "Handshake" between the frontend and the payment gateway to confirm transaction success before triggering database updates.

C. Database Layer

The persistence layer acts as the "Single Source of Truth" for the entire ecosystem.

- Product Repository: Stores master data including Barcode IDs, pricing, and specific product metadata.
- Transaction & Audit Logs: Maintains comprehensive records of all purchases, payment statuses, and timestamps for retail analytics.
- Automated Inventory Management: Executes atomic updates to stock levels immediately upon transaction success, ensuring real-time accuracy and preventing inventory leakage.
- Connectivity: Communicates with the Application Layer via structured SQL queries and optimized API calls to ensure low-latency data retrieval.

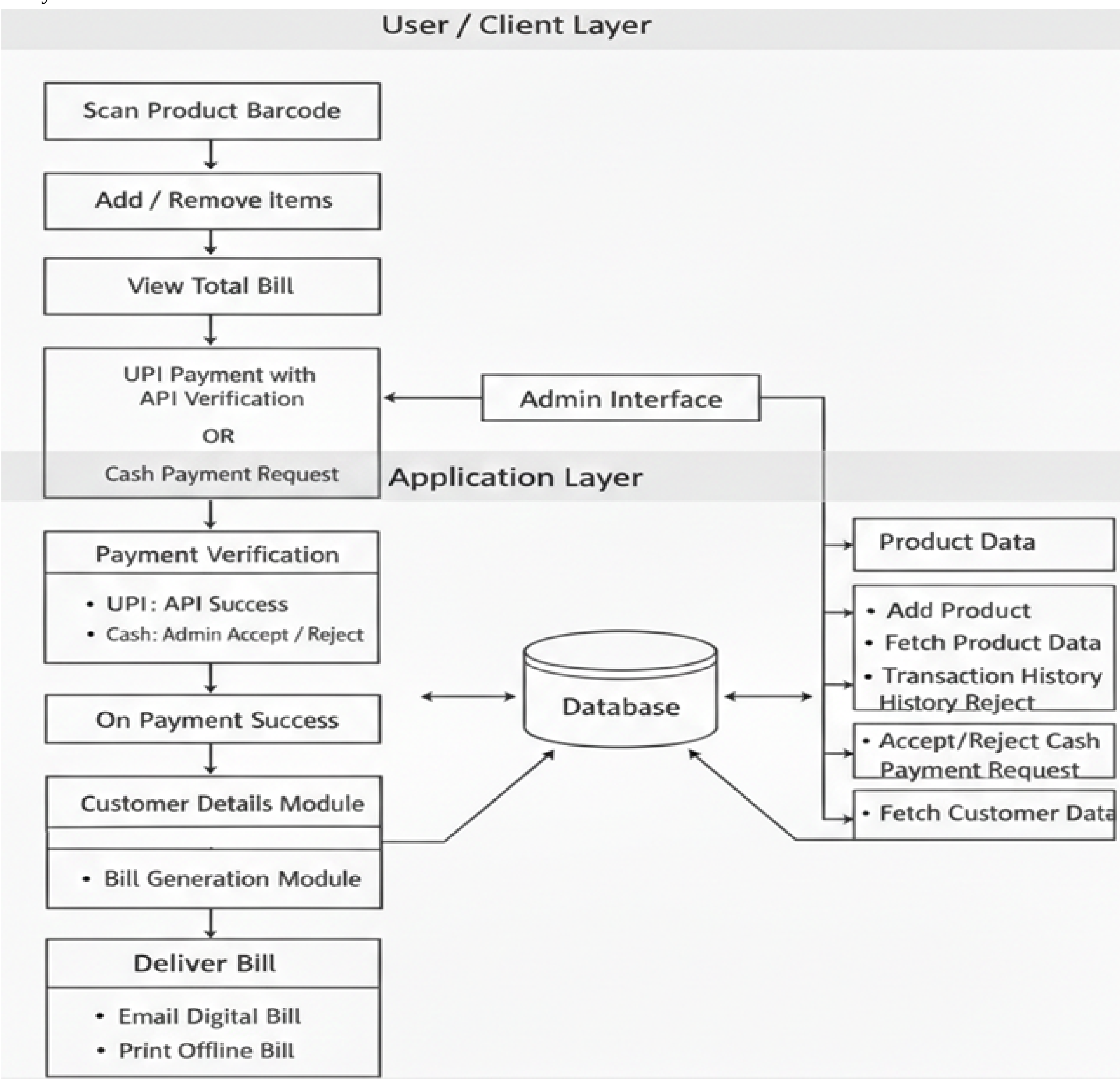

Fig. 1: System Architecture

The Smart E-Cart system is engineered using a modern, decoupled architecture. The selection of the following technologies was predicated on their ability to provide high concurrency, low latency, and cross-platform compatibility [1], [16].

1) Frontend and Computer Vision Framework

- React.js (User Interface Layer): The client-side application is built using React.js, a component-based JavaScript library. Its virtual DOM (Document Object Model) ensures that the digital cart and total bill update instantaneously without a full page reload, providing a fluid "Single Page Application" (SPA) experience [13].
- Quagga2 (Computer Vision Module): For real-time barcode decoding, the system integrates Quagga2, an advanced open-source library written in JavaScript. Unlike traditional scanners, Quagga2 utilizes sophisticated image processing algorithms (such as localization and binarization) to detect and decode EAN or UPC barcodes directly from a device's camera stream [16].
- JavaScript Barcode Generator: This utility is implemented in the administrative module to create unique, machine-readable identifiers for new inventory items, ensuring seamless integration between physical stock and the digital database [9].

2) Backend and Microservices Architecture

- Spring Boot (Application Logic Layer): The backend is developed using the Spring Boot framework, chosen for its "Production-Ready" features and embedded Tomcat server. It handles the core business logic, including price calculation, session management, and transaction security [17].
- RESTful API Architecture: Communication between the React frontend and Spring Boot backend is facilitated through REST (Representational State Transfer) APIs. Using standardized JSON (JavaScript Object Notation) for data exchange minimizes the payload size, ensuring fast response times even on 4G/5G mobile networks [4], [14].

3) Data Persistence and Transactional Security

- Relational Database (PostgreSQL): A robust relational database management system (RDBMS) is utilized to maintain data integrity [11], [20]. It stores multi-dimensional data, including:
  - Product Metadata: SKU, Name, Price, and Barcode ID.
  - Inventory Records: Real-time stock levels with atomic decrementing logic.
  - Transaction Logs: Historical records for auditing and administrative review.
- Payment Gateway API Integration: To ensure secure financial transactions, the system integrates with industry-standard payment APIs (such as Razorpay or Stripe). This ensures that sensitive credit card or UPI information is handled through encrypted, PCI-DSS compliant channels, rather than being stored on local servers [7], [18].

4) Hardware-Software Interfacing

- Mobile-First Design: The system is optimized for mobile browser environments, utilizing the MediaDevices API to access high-resolution camera hardware. This allows for a hardware-agnostic deployment where any smartphone can function as a high-speed scanning kiosk [5], [16].

VII. RESULTS

Experimental testing showed that the Smart E-Cart system provides a smooth and efficient shopping experience. Customers were able to scan products quickly using device cameras and view cart updates instantly.

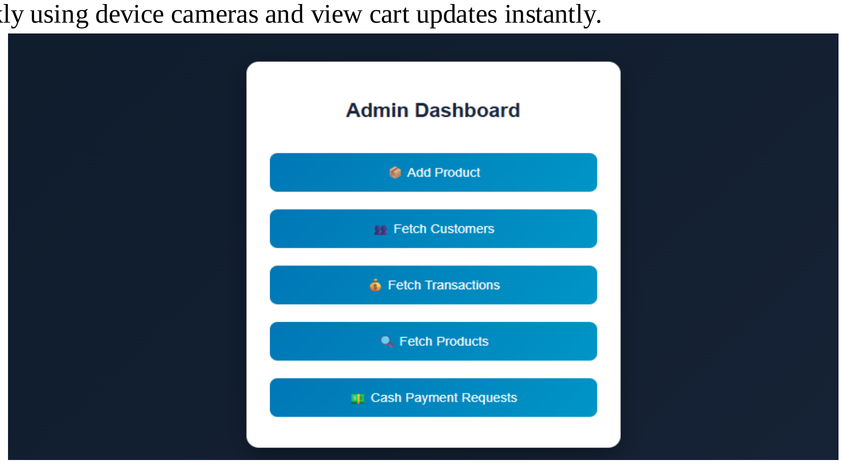

Fig 2.1: Admin interface

The Admin Dashboard serves as a centralized command hub where administrators can seamlessly manage inventory by adding or retrieving product details. It streamlines operational oversight by providing direct access to customer databases and real-time transaction history for better financial tracking. Additionally, the interface simplifies manual accounting by organizing cash payment requests into a clear, actionable list for quick verification.

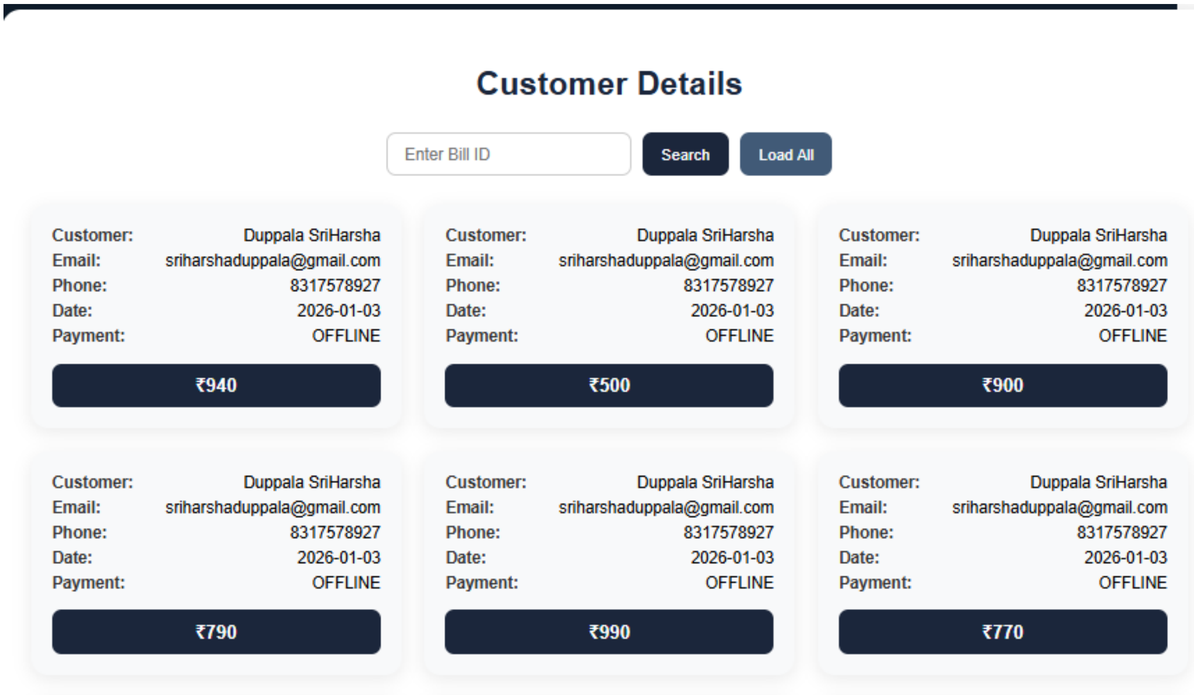

Fig 2.1(b): fetching Customer details

This interface provides a streamlined view for managing customer records, allowing administrators to search for specific bills or load all entries simultaneously. Each card displays essential data including the customer's name, contact details, and transaction dates for quick reference. The clear labeling of payment status and total amounts ensures that financial tracking and manual verification remain efficient and organized.

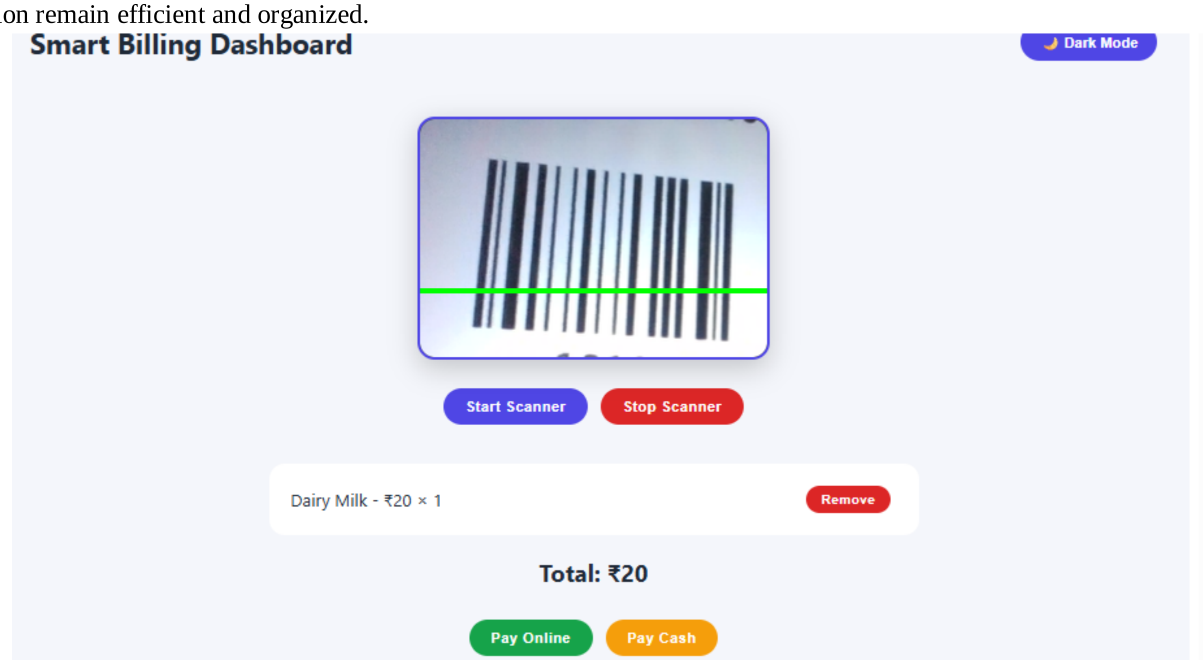

Fig 2.2(a): barcode scanning and adding& removing products in cart

The Smart Billing Dashboard provides a user-friendly interface that integrates real-time barcode scanning to automate the product entry process. Users can easily manage their shopping list by adding items through the scanner or using the "Remove" option to adjust their cart before finalizing the purchase. The interface is rounded off with clear payment triggers, offering both online and cash alternatives to ensure a flexible and efficient self-checkout experience.

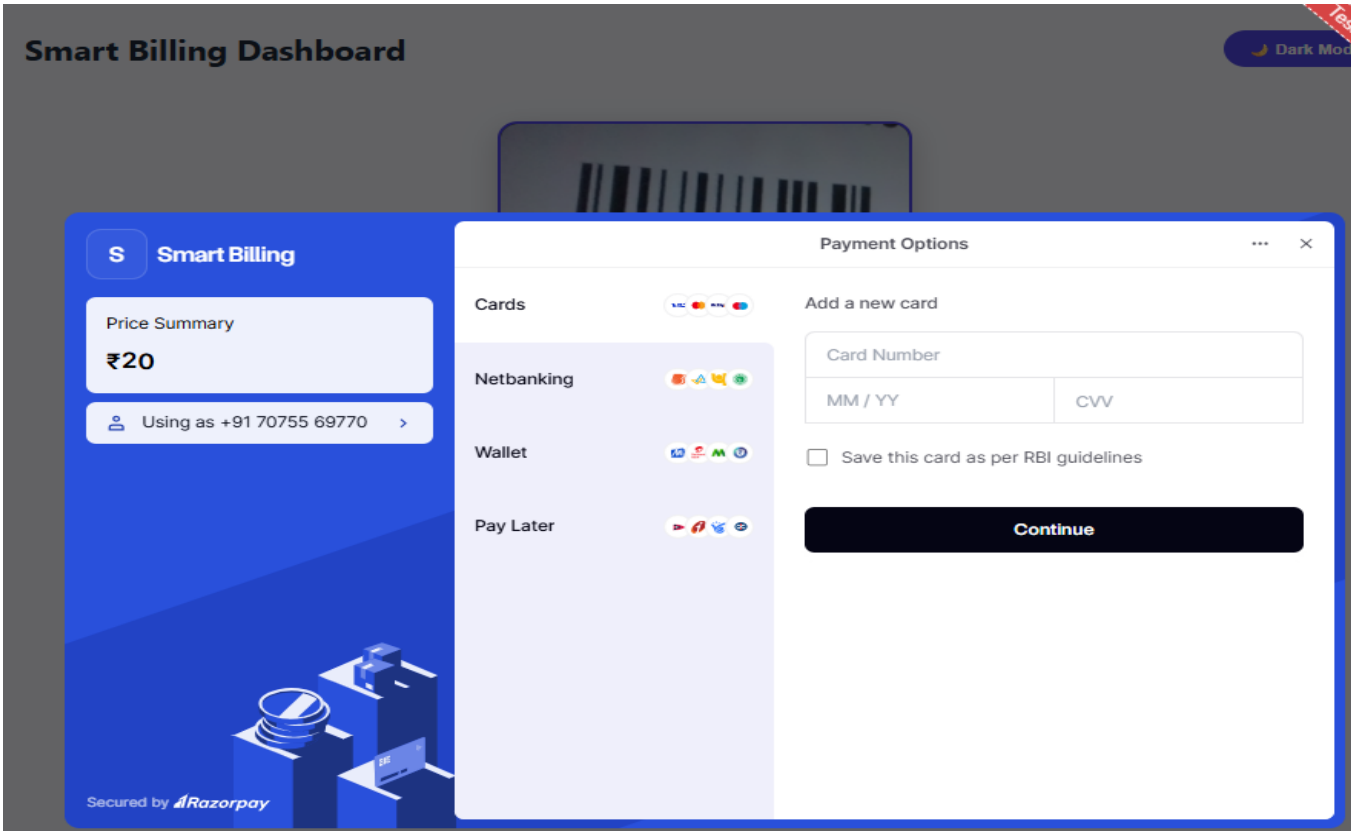

Fig 2.2(b): online payment

The online payment gateway provides a secure and versatile checkout experience by integrating multiple transaction methods such as Cards, Netbanking, and Wallets. This interface ensures compliance with RBI guidelines while offering a clear price summary to keep users informed before they finalize their purchase. Powered by Razorpay, the system delivers a smooth, professional transition from the shopping cart to a successful digital payment.

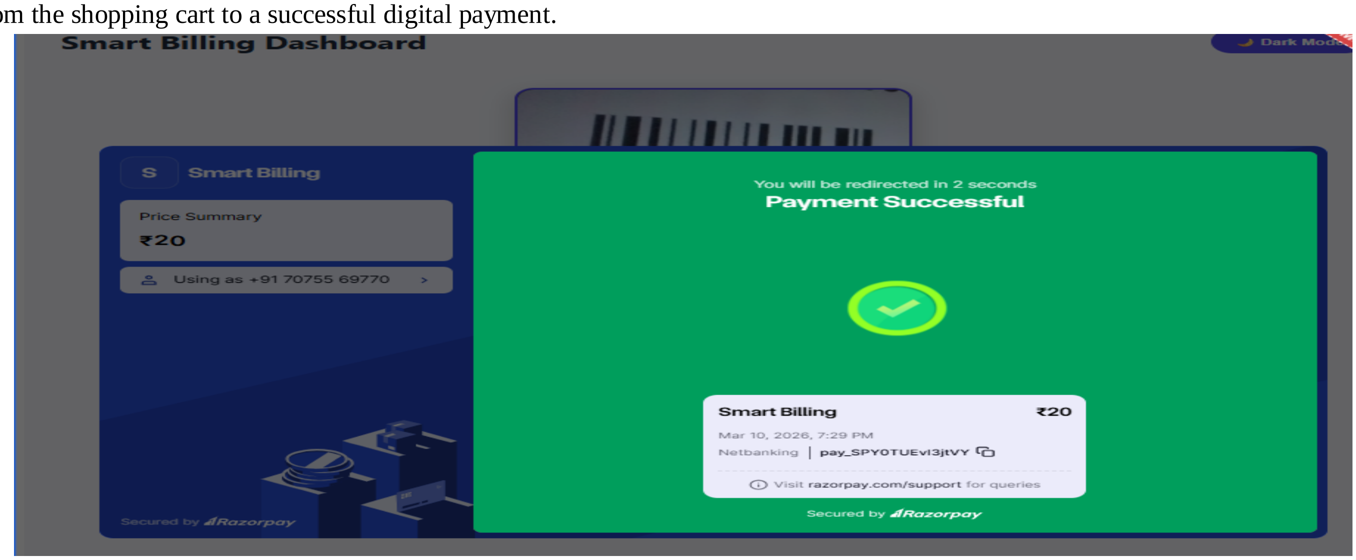

Fig 2.2(c): payment auto verification

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Upon completing the transaction, the system provides an instantaneous confirmation message to reassure the user that the payment was processed successfully. This automated verification screen displays a detailed receipt, including a unique transaction ID and the exact time of the purchase for future reference. To maintain a smooth user journey, the interface includes a timed redirect that automatically returns the shopper to the main dashboard after the successful checkout.

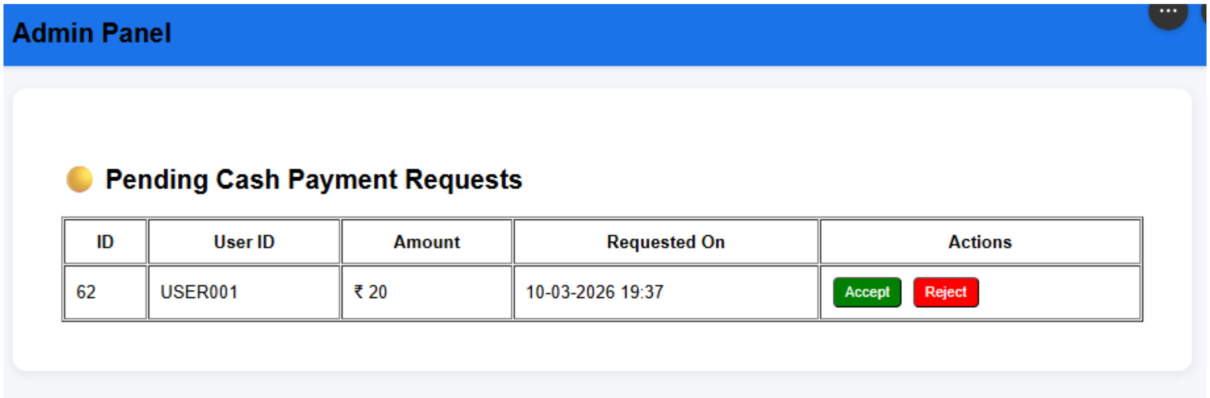

Fig 2.1(d): Accept cash payment in admin interface

The Admin Panel features a dedicated management table for manual oversight, allowing staff to verify and process pending cash payment requests in real-time. Each entry displays specific transaction details, including the User ID, total amount, and precise request timestamp, ensuring full transparency during the auditing process. Administrators can then utilize the "Accept" or "Reject" action buttons to instantly update the payment status and synchronize the billing records within the system.

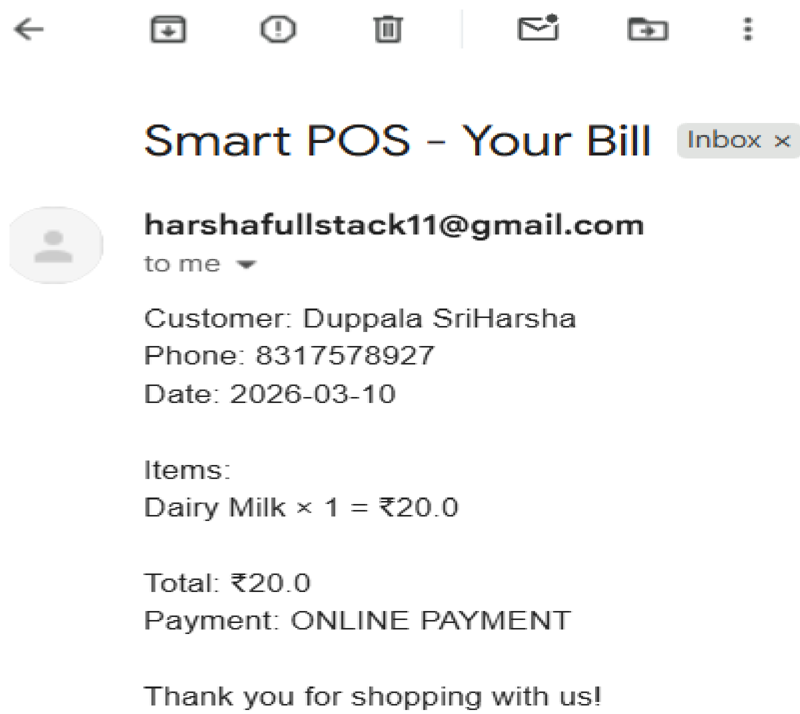

Fig 2.3: Bill to the email

The Smart POS system automatically generates and sends a digital receipt to the user's registered email address upon the completion of a transaction. This electronic bill provides a comprehensive summary, including the customer's contact details, the specific items purchased, and the total amount paid. By documenting the payment method and date, the system offers a convenient and eco-friendly way for shoppers to maintain a permanent record of their shopping history.

The system successfully generated accurate bills and processed payments through the integrated digital payment gateway. Inventory updates are also performed automatically after each purchase.

Compared to traditional checkout systems, the Smart E-Cart platform demonstrated significant improvements in billing speed, accuracy, and customer convenience.

VIII. CONCLUSION

The research presented in this paper successfully demonstrates the design and implementation of an Automated Smart E-Cart System, a paradigm shift in the digital transformation of the retail sector. By moving away from traditional, centralized checkout models that rely on manual human intervention, this system establishes a decentralized, user-centric shopping environment. The integration of the Quagga2 computer vision library for browser-based barcode decoding and a robust Spring Boot microservices architecture provides a seamless bridge between physical product interaction and digital inventory management.

The experimental results confirm that the proposed framework significantly optimizes the "Time-to-Checkout" metric, thereby enhancing the overall consumer experience and operational throughput of the retail outlet. By utilizing a PostgreSQL/MySQL relational database for real-time synchronization, the system ensures high data integrity, effectively eliminating common discrepancies in stock levels and billing totals. Furthermore, the inclusion of multi-modal payment optionsranging from secure online gateways to verified cash requestsensures that the system is inclusive of diverse consumer preferences.

In conclusion, the Smart E-Cart system offers a high-performance, cost-effective, and scalable alternative to expensive RFID-based hardware. It provides a strategic roadmap for small and medium-sized retail enterprises to adopt automation with minimal capital expenditure, ultimately paving the way for the next generation of frictionless "Smart Retail" environments.

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BIOGRAPHIES

Mr. A. Sai Prasad is currently working as an Assistant Professor in the Department of Computer Science and Engineering at Sanketika Vidya Parishad Engineering College, Visakhapatnam. The institution is affiliated with Andhra University and accredited by NAAC. His primary areas of interest include Artificial Intelligence and Machine Learning (AI & ML). He has successfully guided several undergraduate projects focusing on intelligent systems, predictive modeling, and data-driven AI applications.

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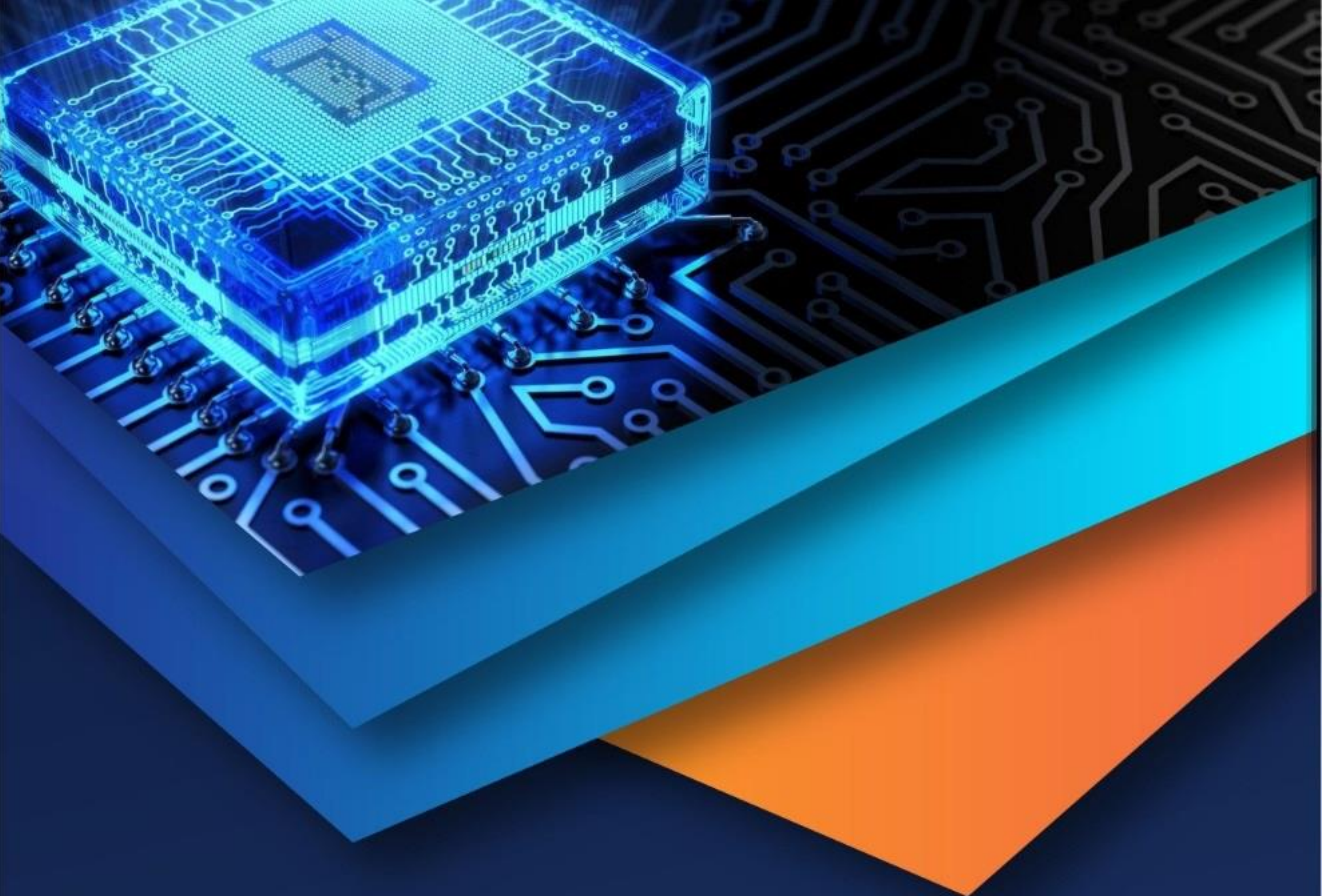

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