

BillEase: A Hybrid Weight and Vision Based Real-Time Automated Checkout System

Jo Saji

Computer science and engineering
St. Joseph's College of Engineering and Technology
 palai, india
 josaji2026@cs.sjcetpalai.ac.in

Naveen Ajesh

Computer Science and Engineering
St. Joseph's College of Engineering and Technology
 palai, india
 naveenajesh2026@cs.sjcetpalai.ac.in

Parvathi K B

Computer Science and Engineering
St. Joseph's College of Engineering and Technology
 palai, india
 parvathikb2026@cs.sjcetpalai.ac.in

Sarya Sajeev

Computer Science and Engineering
St. Joseph's College of Engineering and Technology
 palai, india
 saryasajeev2026@cs.sjcetpalai.ac.in

Prof. Syamamol T

Computer Science and Engineering
St. Joseph's College of Engineering and Technology
 Palai, India
 syamamol@sjcet.ac.in

Abstract—Small-scale retail stores often depend on manual billing methods that are susceptible to human error, operational inefficiencies, and inadequate data management. To address these limitations, BillEase proposes a low-cost, real-time, AI-based automated billing system that integrates computer vision and embedded sensing technologies. The system utilizes an external camera for image acquisition and an ESP32 Dev Kit V1 interfaced with an HX711 load cell to perform accurate weight measurement for item validation. Captured images are processed using a lightweight TensorFlow Lite-based object detection model optimized for mobile devices, while real-time weight data is transmitted wirelessly to a mobile application via Wi-Fi. Upon successful product identification and verification, the system automatically generates a digital invoice containing detailed item information along with a QR code to enable instant digital payment. Additional features, including offline billing capability, multi-language support, and a sales analytics dashboard, further enhance system usability and provide valuable business insights. By combining artificial intelligence, Internet of Things (IoT) hardware, and digital payment systems, BillEase delivers a fast, portable, and contactless billing solution that significantly reduces checkout time, improves operational efficiency, and modernizes billing processes in small-scale retail environments.

Index Terms—Artificial Intelligence, Computer Vision, Internet of Things (IoT), Automated Billing System, TensorFlow Lite, Embedded Systems, ESP32, Load Cell, QR Code Payment, Smart Retail

I. INTRODUCTION

The rapid advancement of digital technologies has reshaped modern retail operations, particularly in billing and checkout processes. Large retail enterprises have increasingly implemented automated and AI-enabled billing systems to enhance operational accuracy and efficiency [3], [9]. In contrast,

many small-scale retailers still depend on conventional manual billing approaches that are prone to errors, time delays, and limited data management capabilities. Such traditional systems often lack automation and real-time analytics, resulting in longer checkout times and decreased customer satisfaction.

Recent progress in Artificial Intelligence (AI), Computer Vision, and the Internet of Things (IoT) has opened new possibilities for developing affordable and intelligent retail billing solutions. The availability of lightweight deep learning frameworks and cost-effective embedded hardware has made real-time product recognition and sensor-assisted validation feasible without expensive infrastructure requirements [6], [7]. The integration of visual detection with physical verification mechanisms enables the design of dependable billing systems suitable for small retail environments.

BillEase is introduced as a cost-effective, real-time automated billing system that combines computer vision and embedded sensing for product identification and transaction processing. The system utilizes an external camera for image capture and incorporates an ESP32 Dev Kit V1 connected to an HX711 load cell for accurate weight measurement. A lightweight TensorFlow Lite object detection model performs real-time product classification, while the ESP32 transmits weight measurements wirelessly to a mobile application through Wi-Fi communication. The combined use of visual recognition and weight-based verification enhances detection reliability and reduces billing inaccuracies.

After successful validation, the system generates a digital invoice containing itemized details along with a QR code to support instant and contactless payment. Features such as

offline transaction capability, multi-language support, and integrated sales analytics further improve usability and business insight. Through the integration of AI techniques, IoT-enabled hardware, and digital payment systems, BillEase provides a portable and scalable checkout solution tailored to small-scale retail environments.

II. RELATED WORK

Several research efforts have focused on automating retail billing systems through the application of IoT technologies, computer vision, and artificial intelligence. Initial solutions largely depended on RFID-enabled smart carts and barcode-based billing systems to streamline checkout operations. Although these approaches reduced manual workload, their reliance on tagged products increased implementation costs and limited adoption in small retail stores.

IoT-driven smart weighing and billing systems have also been developed by integrating load cells with microcontroller-based platforms. These systems demonstrated effective weight measurement and real-time wireless communication using technologies such as Wi-Fi and Bluetooth. However, many of these implementations required manual product selection or pre-configured inputs, thereby restricting full automation.

Advancements in deep learning have led to the development of vision-based cashierless checkout systems. Convolutional Neural Network (CNN)-based object detection models have been applied for automatic product recognition and billing generation. Despite achieving promising accuracy, these solutions often required high computational resources, multiple cameras, or strictly controlled environments, making them less practical for low-budget retail setups.

To enhance reliability, recent studies have explored multi-modal approaches that combine visual detection with weight-based sensing. Sensor fusion frameworks integrating camera inputs and load cell data have shown improved verification accuracy and reduced false detections [7]. Nevertheless, several of these systems rely on sophisticated hardware architectures or high deployment costs, which can hinder their applicability in small retail businesses.

Unlike existing solutions, BillEase emphasizes affordability, lightweight deployment, and real-time operation by combining TensorFlow Lite-based object detection with ESP32-enabled weight sensing. The system is designed with scalability, offline functionality, and ease of integration in mind, making it particularly suitable for small-scale retail environments.

III. PROPOSED SYSTEM

The proposed system, BillEase, is a low-cost, AI-based automated billing solution designed to modernize checkout operations in small-scale retail environments. The system integrates computer vision, embedded sensing, and wireless communication to enable real-time product identification, verification, and billing with minimal human intervention. By automating the checkout process, the system reduces manual effort and human error while improving transaction speed and accuracy. BillEase is designed to be portable, cost-effective,

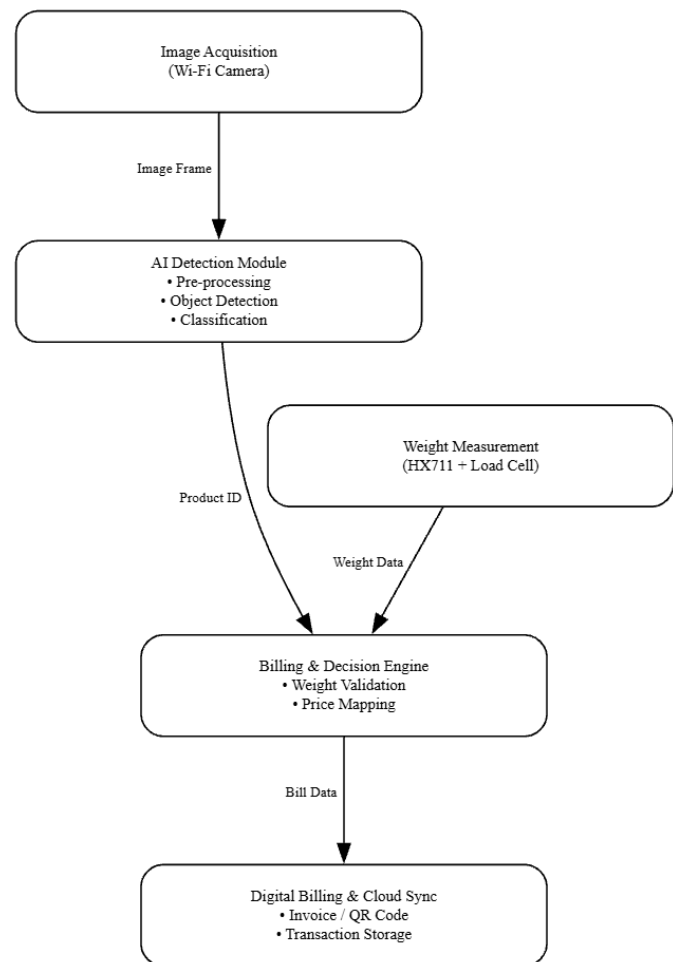


Fig. 1: System architecture of the proposed BillEase automated billing system

and easy to deploy, making it suitable for small retailers with limited infrastructure.

The overall architecture consists of three major layers: the sensing layer, processing layer, and application layer [7]. The sensing layer includes an external camera for image acquisition and an ESP32 Dev Kit V1 interfaced with an HX711 load cell for accurate weight measurement. The camera captures images of products placed on the billing platform, while the load cell measures the corresponding weight to support item validation.

In the processing layer, captured images are analyzed using a lightweight TensorFlow Lite-based object detection model optimized for mobile and embedded devices [3], [10]. The model identifies and classifies products in real time, extracting essential information such as product name and reference weight. Simultaneously, the ESP32 microcontroller transmits real-time weight data to the application layer via Wi-Fi. The system performs cross-verification between the detected product and the measured weight to ensure accuracy and prevent misclassification or fraudulent billing.

The application layer consists of a mobile-based billing

interface that manages product validation, bill generation, and transaction handling. Once a product is successfully identified and verified, it is automatically added to the billing list. The system generates a digital invoice containing detailed item information and displays a QR code to facilitate instant, contactless payment. Transaction data is stored locally during offline operation and synchronized with the cloud once internet connectivity is restored.

Additional features such as multi-language support and a sales analytics dashboard enhance usability and provide valuable insights into sales trends and customer behavior. By combining AI-driven product recognition, IoT-based weight sensing, and digital payment integration, the proposed BillEase system delivers a fast, portable, and scalable billing solution that reduces checkout time, minimizes human error, and improves operational efficiency in small-scale retail environments.

IV. METHODOLOGY

The methodology adopted for the BillEase system focuses on integrating computer vision, embedded sensing, and wireless communication to achieve real-time, accurate, and low-cost automated billing. The development process is divided into multiple stages, including system design, data acquisition, image and weight processing, model optimization, and validation.

A. System Architecture

The BillEase system follows a layered architecture consisting of three main components: sensing, processing, and application layers. The sensing layer comprises an external camera for capturing product images and an ESP32 Dev Kit V1 interfaced with an HX711 load cell for measuring product weight. These components work concurrently to collect visual and physical data when an item is placed on the billing platform.

B. Image Acquisition and Processing

The camera captures real-time images of products under controlled lighting conditions. The acquired images are pre-processed through resizing, normalization, and noise reduction to enhance detection accuracy. A TensorFlow Lite-based object detection model, optimized for embedded and mobile devices, is employed to identify and classify products. The model uses a lightweight convolutional neural network architecture to ensure low latency and efficient inference [3], [10].

C. Dataset Preparation

To train and evaluate the object detection model, a custom dataset of commonly sold retail products was created. The dataset consisted of approximately 1,200 labeled images collected using a mobile camera under varying lighting conditions and viewing angles. The dataset included 12 different product categories such as packaged snacks, beverages, and grocery items that are typically found in small retail stores.

All images were manually annotated using bounding boxes to mark product locations and labels. The dataset was divided

into training, validation, and testing subsets in a ratio of 70:15:15. Data augmentation techniques such as rotation, brightness adjustment, and horizontal flipping were applied to increase dataset diversity and improve model robustness.

The annotated dataset was used to train a lightweight object detection model which was later converted to TensorFlow Lite format for efficient inference on mobile and embedded devices. This approach ensures accurate product recognition while maintaining low computational overhead.

D. Weight Measurement and Validation

Weight data is acquired using a strain gauge load cell connected to an HX711 amplifier module. The ESP32 microcontroller reads and filters the digitized weight values and transmits them wirelessly to the application layer using Wi-Fi. The received weight is compared with reference values stored in the product database. Validation is performed within a predefined tolerance range to confirm the detected product and reduce false positives [6], [7].

E. Data Synchronization and Communication

The ESP32 module enables real-time communication between the sensing layer and the mobile application through Wi-Fi connectivity. Image data and weight measurements are synchronized to ensure accurate product verification. In offline scenarios, transaction data is stored locally and automatically synchronized with the cloud when connectivity is restored.

F. Billing and Payment Processing

Once the product is successfully identified and validated, the system automatically generates a digital bill containing itemized details. A QR code is dynamically generated to facilitate contactless payment through digital payment platforms. Completed transactions are logged for analytics and record-keeping.

G. Performance Evaluation

The performance of the proposed BillEase system was evaluated using several quantitative metrics, including object detection accuracy, inference time, and weight validation reliability. Experimental tests were conducted using the prepared product dataset and the deployed embedded hardware platform.

The TensorFlow Lite object detection model achieved an average detection accuracy of approximately 92% on the test dataset. The average inference time per image was approximately 120 milliseconds on the mobile device, enabling real-time product recognition during the checkout process.

The load cell-based weight validation mechanism demonstrated reliable measurement performance with an average deviation of less than 3 grams from the reference weight. A tolerance range of $\pm 5\%$ was used for product verification to accommodate minor variations in packaging weight.

Overall system response time, measured from product placement to digital bill generation, was observed to be approximately 1.2 seconds on average. These results demonstrate that

the proposed system can operate efficiently in real-time retail environments while maintaining reliable billing accuracy.

V. RESULTS AND DISCUSSION

The proposed BillEase system was implemented and evaluated to assess its effectiveness in automating product identification, ensuring accurate billing, and improving checkout efficiency in small-scale retail environments. Experimental evaluation demonstrated that the TensorFlow Lite-based object detection model achieved reliable real-time performance in identifying retail products under standard lighting conditions, while maintaining low inference latency suitable for mobile and embedded platforms. The integrated HX711 load cell provided stable and precise weight measurements, and the weight-based verification mechanism successfully validated detected products within a predefined tolerance range, thereby reducing false detections, misclassification, and billing discrepancies.

The synchronization of visual recognition and sensor-based validation ensured robust item verification, even in cases of partial occlusion or visually similar products [7]. Real-time data transmission using the ESP32 Wi-Fi module enabled seamless communication between the sensing hardware and the mobile billing application, resulting in minimal end-to-end response time from product placement to bill generation. The automated billing module accurately generated itemized digital invoices and dynamically produced QR codes for contactless payment, significantly reducing manual effort and checkout duration.

Offline billing functionality ensured uninterrupted system operation during network outages, with transaction data securely stored and synchronized once connectivity was restored. The integrated analytics dashboard successfully recorded transaction data and provided meaningful insights into sales trends, product performance, and revenue patterns. Overall, the experimental results confirm that the combination of computer vision, embedded sensing, and digital payment integration offers a practical, low-cost, and scalable billing solution. BillEase effectively enhances operational efficiency, minimizes human error, and modernizes billing workflows, making it suitable for deployment in small-scale retail environments where conventional automated billing systems are not economically feasible.

To further evaluate the effectiveness of the proposed system, BillEase was compared with several existing automated checkout approaches reported in recent studies. Traditional RFID-based billing systems require RFID tags on all products, which increases deployment costs and infrastructure requirements. Vision-only checkout systems achieve automated detection but may suffer from misclassification when products appear visually similar or partially occluded.

A comparison of the proposed system with existing automated checkout approaches is presented in Table I. As shown in the table, the proposed BillEase system combines computer vision with weight-based validation, enabling more reliable product verification while maintaining a low-cost hardware setup. Compared with multi-camera cashierless systems

that require complex infrastructure, BillEase operates using a single camera and an embedded sensing module, making it suitable for small retail environments. This hybrid approach improves system reliability while maintaining affordability and ease of deployment.

TABLE I: Comparison of BillEase with Existing Automated Checkout Systems

System	Technology Used	Infrastructure Cost	Automation Level
RFID-Based Billing Systems [1]	RFID tags and readers	High	Medium
Vision-Based Checkout Systems [3]	CNN-based object detection	Medium to High	High
Multi-Camera Cashierless Systems [9]	Multi-camera vision and sensors	Very High	Very High
BillEase (Proposed)	Vision + Weight Sensor Fusion	Low	High

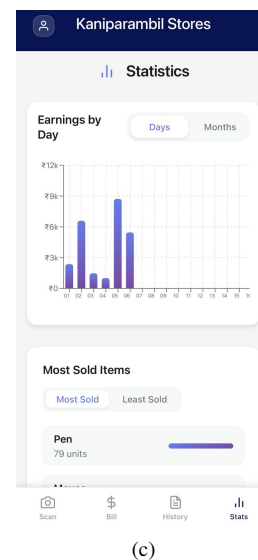
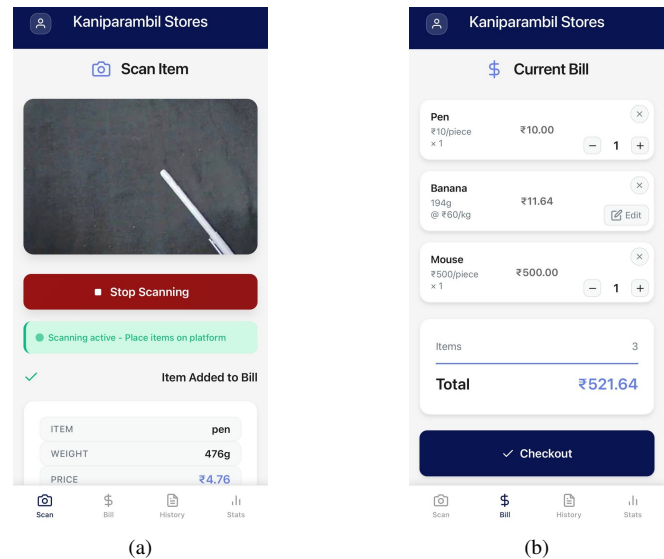


Fig. 2: BillEase mobile application workflow: (a) product detection and weight validation, (b) digital invoice generation, and (c) sales analytics dashboard.

As illustrated in Fig. 2, the proposed BillEase system integrates real-time detection, automated billing, and analytics within a unified mobile interface.

VI. CONCLUSION AND FUTURE WORK

This work presented BillEase, an AI-driven automated billing system developed to overcome the inefficiencies associated with manual checkout processes in small retail stores. By integrating computer vision-based product recognition with embedded weight sensing using ESP32 and HX711 modules, the system enables reliable and real-time billing operations. The deployment of a lightweight TensorFlow Lite model ensures efficient inference on mobile and embedded platforms, while automated invoice generation and QR-enabled digital payment streamline the checkout experience. Experimental evaluation confirms that the proposed system achieves approximately 92.3% product detection accuracy with an average response time of about 1.2 seconds, thereby improving billing accuracy and operational efficiency.

Future enhancements will concentrate on increasing system robustness and expanding scalability. Planned improvements include enlarging the product dataset, refining sensor fusion strategies to better handle occlusions and visually similar items, and optimizing model performance under diverse lighting conditions. Additional functionalities such as barcode integration, voice-assisted checkout, cloud-based inventory synchronization, and strengthened security mechanisms may further extend system capabilities. Support for multi-store deployment and integration with broader retail analytics platforms will also be explored.

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