Research Article

A Smart Shopping Cart: Shopper®

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Abstract

This study presents the design and development of Shopper®, a smart shopping cart system that integrates embedded hardware, computer vision, and real-time localization technologies to enhance the in-store shopping experience. The system combines a custom control panel, dual-camera based barcode recognition architecture, loadcell weight tracking, and a mobile-based authentication mechanism. The Shopper® autonomously verifies items, updates shopping cart contents, and initiates automatic checkout when reaching designated payment zones. By merging user experience design (UX) principles with embedded IoT hardware, the solution reduces queue times and enriches the consumer's shopping journey. The results indicate a significant improvement in *transaction speed and customer satisfaction, supporting the viability of smart carts as an effective bridge between physical and digital retail ecosystems.*

Keywords: Embedded Design, Computer Vision, Deep Learning, IoT, UX, RTLS, Smart Shopping Cart.

1. Introduction

Smart shopping carts are increasingly recognized as transformative innovations in retail sector, combining convenience, efficiency, and novel customer experiences. Research highlights that functional benefits such as time savings and ease of use are among the primary drivers of adoption, with consumers weighing these advantages against concerns about risk and privacy [1]. From an operational perspective, simulation studies demonstrate that even partial implementation of smart shopping carts can significantly reduce waiting times, optimize staffing, and enhance overall store efficiency [2]. Industry data also highlights the commercial momentum of this technology: the global smart shopping cart market was valued at USD 1.72 billion in 2024 and is forecast to grow to USD 5.29 billion by 2029 [3]. Retail pilot projects reinforce this promise, reporting customer retention rates above 95% and substantial monthly savings from reduced cart loss and enhanced shopper engagement [4]. Collectively, these findings illustrate both the consumer and business value of smart carts, while underscoring the importance of thoughtful design and strategic deployment.

2. Materials and Methodology

The Shopper® - Smart Shopping Cart – as shown in Figure 1, integrates hardware and software subsystems designed to deliver a seamless shopping experience.
The architecture is divided into four primary layers:
(1) Embedded hardware Layer: For sensor data acquisition, power management, and weight measurement;
(2) UX/UI Layer: For user interaction, authentication, and payment interface;
(3) Mobile Application Layer: For both authentication and declaring a payment method (a valid credit or debit card);
(4) Computer Vision Layer: For product identification through barcode and visual processing.
This layered structure follows modular IoT design principles as emphasized by Aydin, Jaweesh, AlHunaiyyan, Mansour, M [2].

Figure 1: Shopper® Smart Shopping Cart

2.1 Materials

2.1.1. Control and Embedded Hardware

The Electronic Control Unit (ECU) manages battery charging, power distribution, and sensor data communication. The 12V Li-ion battery powers all components, with safety circuitry ensuring stable operation. Four precision load cells at the cart's corners measure product weight, providing accurate tracking of insertions and removals. Proximity and infrared sensors trigger barcode capture events. RGB LEDs feedback to user, while illumination LEDs ensure optimal lighting for image capture. The Real-Time Location System (RTLS) continuously tracks cart position for automated checkout.

2.1.2. User Interface and Interaction Hardware

The control panel, mounted behind the handlebar, hosts a touchscreen display for customer interaction. A QR code reader on the right side of the panel authenticates the user via mobile application. The control panel serves as the main interface, communicating with the ECU providing real-time shopping feedback.

2.1.3. Mobile Application

A custom mobile application designed and developed in order to be used in logging phase and payment method declaration. It is also required for registration of new accounts (Figure 2-a). It is responsible for both QR log in (shown in Figure 2-b) and credit card (payment method) registration as shown in Figure 2-c.

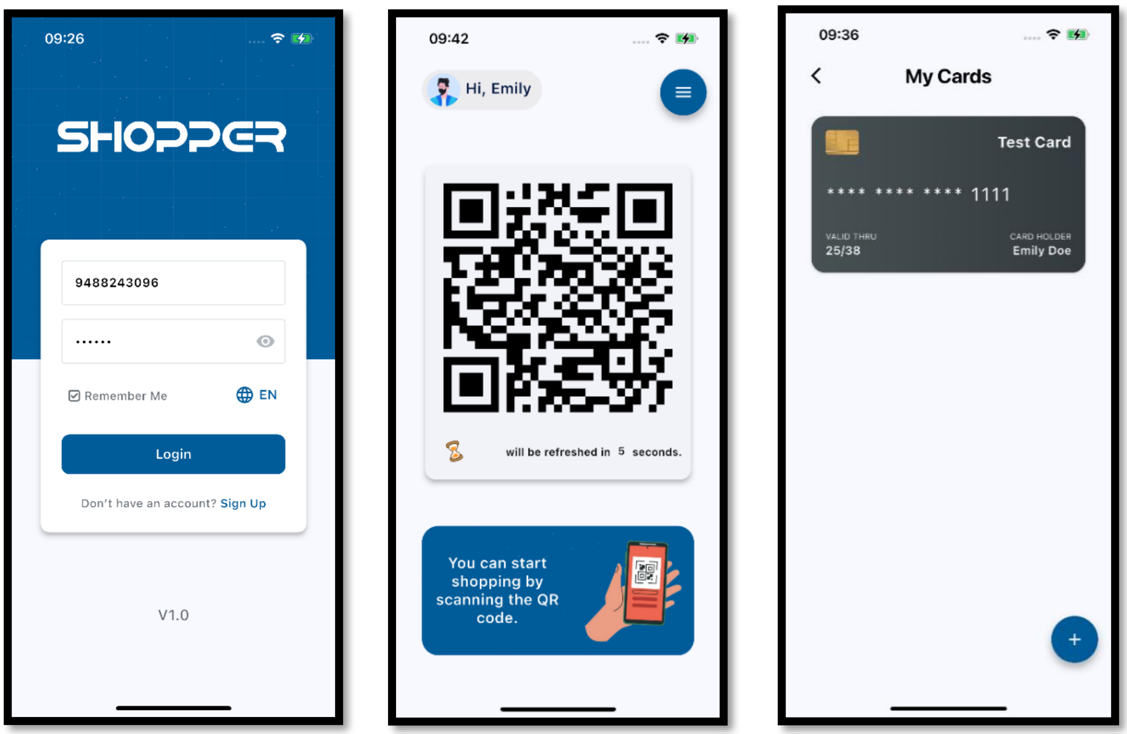

Figure 2: Mobile application pages

(a): Registration page *(b): Login with QR code page* (c): *Payment registration page*

2.1.4. Computer Vision and Camera System

A Single Board Computer performs Deep Learning (DL) inference for barcode detection. Two cameras are used: Global Shutter camera for motion-free capture and an Autofocus camera for detailed imaging. This dual-camera setup improves robustness under variable lighting and motion. The illumination LEDs and proximity sensor were used in embedded hardware to enhance the vison of the two cameras.

2.2. Methodology

The methodology includes sequential flows: authentication, barcode recognition , load-cell monitoring, , UX/UI feedback, and checkout automation. The mobile application is essential for Shopper® since it requires an account on the mobile application which is used for logging in and to start Shopper® experience. The application also provides a secure logging in with the QR code that randomly generated by the mobile application. Shopper® checks that code from the database to ensure its validity. The mobile application is required registration of the payment method as well. During initialization, the customer logs in by scanning a QR code generated by the mobile application, thus links the user account to that cart. Loadcells constantly measure weight differences, triggering verification when discrepancies occur. This leads Shopper® that detect the products put inside or being removed. The database contains each item's weight and the Shopper® compares the item's weight and related database information to check if it is valid. Barcode images captured by the dual-camera system are processed using a custom trained DL model and decoded via the barcode decoder library (Zxing-C++ Community, 2024) [5]. The dual-camera system utilizes illumination LEDs and proximity sensor that are embedded inside the Shopper® since they designed to increase the visual range and barcode reading distance. The barcode data which captured and decoded by the dual-camera system is compared to valid barcode data inside the database in order to check its validity. Through the Control Panel customer/user has access to Shopper® UI (Figure 5) and they can follow their shopping. The UI of Control Panel and RGB LEDs provide user feedback in accordance with human-centered UX guidelines [1], and they have been designed to work together and to increase heuristic sense of experience and to assist customers to use Shopper® The RGB LED lights are beneficial since the lights are categorized into groups in order to inform customers about success, error and idle actions without using screen interaction. The red tones are using for error feedback, the green tones are for successful barcode read and accepted user actions, the blue tones mean the Shopper® is waiting command or process.

The Shopper® 's location is monitoring by the UWB-Based RTLS inside the market. The RTLS coordinates trigger the payment interface automatically at checkout zones, following autonomous retail models [2, 3].
In the purpose of test and calibration, a developer console added into the software. From the console; location parameters of RTLS, light intensity of illumination, LED and proximity sensors' range for DOF (Depth of Field) of cameras. Thus; cameras, RTLS, etc. can be calibrated according to different light condition and position.

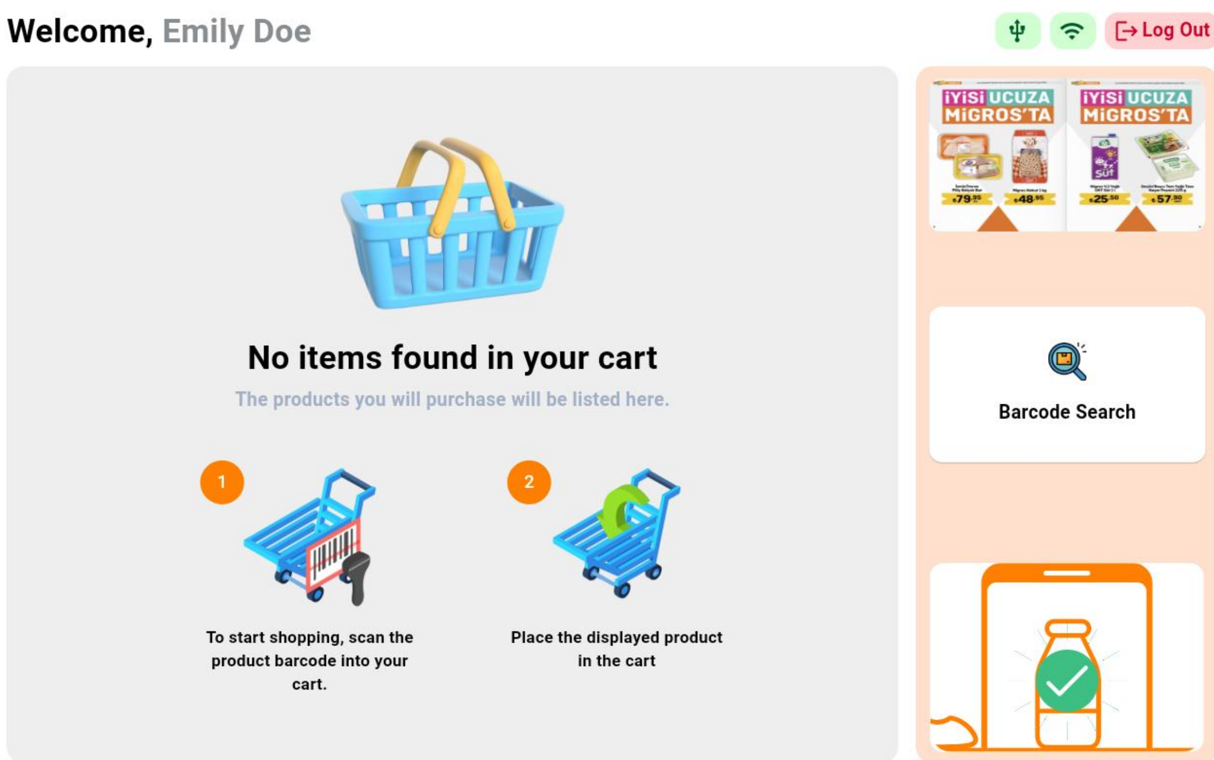

Figure 1: UI of Shopper®

3. Results

Field trials with the Shopper® prototype demonstrated measurable efficiency gains. Checkout time was reduced and item insertion/removal detection accuracy reached 100%. The correct barcode reading rate is measured at 98% which is considered robust. These findings affirm that integrating embedded IoT systems with adaptive UX design enhances operational efficiency and customer satisfaction.
Overall, Shopper® demonstrates that implementation of AI redefines and simplifies people's daily life routines such as retail experiences.

4. Discussion and Conclusion

The Shopper® Smart Shopping Cart exemplifies the convergence of IoT, embedded design, and computer vision in retail sector. The system's automatic product verification and location-based checkout specifications align with trends identified in recent smart retail research [1, 2]. Enhanced UX feedback mechanisms minimize cognitive effort and increase trust. Some benefits of Shopper® Smart Shopping Cart are reducing labor costs and data-driven marketing opportunities.

Future works should focus on long-term usability, AI-driven computational photography techniques and inventory integration, AI-based product matching, power management, online provisioning and data security, etc…

5. Acknowledge

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