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DESIGN OF IOT-ENABLED SMART SHOPPING CART

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Abstract: The rapid expansion of the Internet of Things (IoT) presents a viable solution to inefficiencies in traditional brick-and-mortar retail, particularly the problem of lengthy checkout queues [7, 8]. This paper details the design and implementation of a cost-effective, IoT-enabled smart shopping cart that addresses key practical limitations found in existing systems. Our proposed design incorporates a novel **Hybrid Scanning Mechanism**—integrating both a Radio Frequency Identification (RFID) reader and a Non-RFID (Barcode/QR) reader to ensure universal compatibility with both tagged and untagged supermarket items. Critically, the system introduces a **Real-Time Weight Sensor (Load Cell)** to perform robust anti-theft validation by matching the physical weight of items with the accumulated digital bill, preventing item substitution. The system utilizes an Arduino microcontroller, an ESP module for wireless connectivity, and Bluetooth for communication with a customer's mobile device, achieving the primary objectives of automated billing, queue reduction, and enhanced transaction security. Experimental validation demonstrates that the hybrid approach offers a practical, scalable, and secure alternative to current single-technology smart cart prototypes.

Keywords: IoT, Smart Shopping Cart, RFID, Load Cell, HX711[ESP module], MFRC522[Wi-Fi module].

I. INTRODUCTION

The evolution of retail from traditional shopping to smart environments has been driven by the need to improve customer convenience and opera- tional efficiency [5,10]. Traditional shopping often results in customer frustration due to long checkout lines, uncertainty about the final bill, and the time-consuming process of manual product scanning [8]. The integration of IoT technology—connecting everyday objects to the internet to share data offers a transformative solution by automating the core functions of the shopping process.
The fundamental objectives of this project are threefold:
1) **Eliminate Checkout Queues:** Achieve seamless, automated billing at the cart itself [5,8].
2) **Ensure Billing Accuracy and Security:** Incorporate physical validation to detect fraud and substitution.
3) **Enhance Customer Experience:** Provide real-time cost updates and an organized shopping process.
The distinct contribution of this work is the development of a hybrid, cost-effective architecture that solves the practical limitation of using RFID exclusively. By integrating both RFID and Non-RFID reading capabilities along with physical weight validation, the system is designed to be truly retailer-ready and robust against common inventory and security failures.

II. LITERATURE SURVEY

In their paper [1], Srinidhi Karjol, Anusha K. Holla, and C. B. Abhilash [2018] aimed to depict a reasonable and cost-effective Smart Shopping Cart utilizing IoT innovations to lessen manual labor and enhance the shopping experience. The proposed system provides the nearest route to pick up listed items across different racks. A standout feature is the "Cart-to-Cart communication," which allows customers to share shopping lists with co-shoppers for parallel shopping. The design utilizes weight sensors to detect new or removed items and includes an anti-theft program to prevent checkout without payment.

In their paper [2], Rutwij Kulkarni, Ashutosh Pratap Singh, Aditya Kumavat, and Aman Jha [2023] presented the creation of a smart shopping cart incorporating an automated billing system using Arduino microcontroller technology. The system leverages RFID technology for product identification and weight sensors for real-time inventory

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management. By synchronizing the billing system with the cart, the checkout process is made swift and hassle-free, reducing human error in manual price entry. The paper provides a comprehensive implementation outline covering both hardware components and software algorithms.

In their paper [3], George Suciu, Cristiana Istrate, Cristian Balanean, Hussain Ijaz, Adrian Pasat, and Rafaela Matei [2020] advanced an inno- vative smart shopping platform based on IoT solutions for customer-oriented marketing. The architecture covers image processing techniques to generate digital maps and utilizes Bluetooth Low Energy (BLE) beacons for precise indoor location tracking with an accuracy of approximately
1.5m. Additionally, the platform integrates smart parking sensors to guide customers toward free parking spaces via an enriched mobile application.

In their paper [4], Jian Wang [2025] explored the application of IoT technology to enhance the e-commerce shopping experience in smart stores through RFID-enabled smart carts. The study compares IoT architectures implemented within cloud and fog computing frameworks to reduce processing latency. A neuro-fuzzy approach is employed to optimize decision-making and routing, significantly reducing path congestion and energy waste. The system automatically updates cart details and facilitates seamless billing directly from the trolley.

In their paper [5], Carsten D. Schultz and Patrick Zacheus [2025] explored whether customers are willing to use digital innovations like smart shopping carts in stationary grocery retailing. Using a mixed-method approach of surveys and interviews, they found that customers prioritize ease of use and utility over privacy risks or temporary enjoyment. The study highlights that functional benefits, such as reduced checkout times and shopping comfort, are the primary drivers for adoption.

In their paper [6], Shuvabrata Dey and Tulip Bera [2023] presented a smart, multi-purpose IoT embedded system device based on the ESP32 microcontroller. While designed as a versatile health and wellness tracker, the device is capable of being reprogrammed for various automation roles, including as a system controller. It measures environmental data like temperature and humidity, transmits it to an IoT server via Wi-Fi, and can communicate with a custom Android app via Bluetooth.

In their paper [7], Tapan Kumar Das, Asis Kumar Tripathy, and Kathiravan Srinivasan [2020] proposed a smart trolley design to automate shop- ping and billing to eliminate long checkout queues. The system utilizes Arduino, RFID readers, and an ESP8266 Wi-Fi module to interact with a centralized database. Customers receive an e-bill via email upon completion, and the system allows for remote database management and customer tracking by the store administrator.

In their paper [8], Swetha K B, Abhishek G, Ruthvik T, Meghana B N, and N. R. G. Naresh [2021] surveyed IoT-based smart shopping cart technologies designed to eliminate time-consuming billing processes. The system consists of RFID sensors, an Arduino microcontroller, and a mobile application that displays real-time product information. Information is sent wirelessly to a server for automatic bill generation, and the app allows customers to manage their shopping list based on their budget.

In their paper [9], D. Ferlin Deva Shahila, Ashwini. A, Valantina Stephen, Ezhil E. Nithila, Banu Priya Prathaban, and D. Vedheep [2024] designed and developed ”CannyCart,” an IoT-enabled smart trolley for easy shopping. The system uses RFID to identify items and incorporates weight de- tection to automate billing. A Long Short-Term Memory (LSTM) recurrent neural network architecture is utilized to train product data, achieving a high accuracy of approximately 97% through batch normalization.

In their paper [10], Rodrigo Toconas Ocaña, Sergio Andres Mego Peñaranda, and Victor M. Parasi Falcon [2024] evaluated the efficiency of an experimental checkout system utilizing RFID and AWS facial recognition. The system demonstrated significant efficiency improvements, reducing checkout times by approximately 73% during low activity and 84% during high activity. While younger users (18-30) showed a 100% preference for the system, older users (51-70) faced more challenges with the facial recognition interface, indicating a need for better UI design for older demographics.

III. DESIGN AND IMPLEMENTATION

A Proposed Methodology / System Architecture

The proposed system combines RFID-based identification with load-cell-based weight validation. Its core function is

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to capture product data, perform physical validation through real-time weight measurement by comparing the measured item weight with its estimated reference value, compute the total bill, and transmit the verified data for secure, cashless checkout, thereby preventing item theft or substitution.The ESP8266 microcontroller processes RFID data, validates weight changes, updates billing information, and communicates with a mobile device.

B Block Diagram

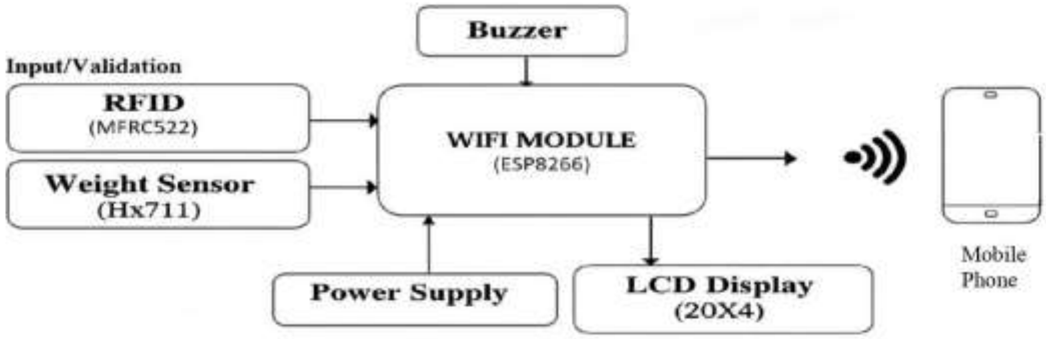

Figure 1: Block Diagram of the Proposed IoT-Enabled Smart Shopping Cart The system comprises six main functional blocks (See Fig. 1):

1. **Input/Scanning Modules:** RFID Reader and Non-RFID Reader (Barcode/QR).
2. **Validation Module:** High-precision Weight Sensor (Load Cell).
3. **Processing Unit:** Arduino Microcontroller.
4. **Communication Module:** Wi-Fi Module (ESP8266/ESP32) and Bluetooth.
5. **Output/Feedback:** Buzzer and Mobile Application Interface.
6. **Power Supply:** External Power Source or Battery.

C Load Cell Operation and Wheatstone Bridge Principle

The **Load Cell (10kg Model)** is the central component of our anti-theft validation system. It is a transducer that converts mechanical force (weight) into a measurable electrical signal. We utilize a 10kg capacity model, appropriate for the typical load of a supermarket cart.

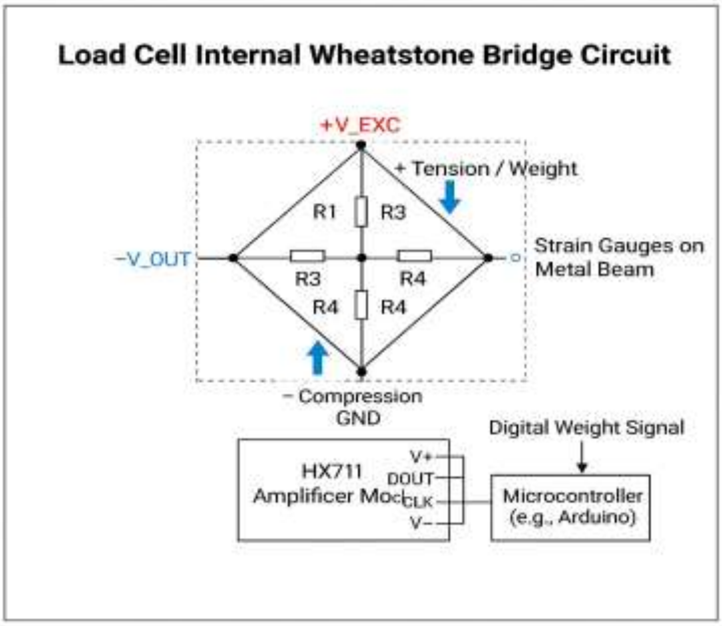

Figure 2: Load Cell Internal Wheatstone Bridge Circuit with HX711 Interface

• **Internal Working: Wheatstone Bridge Principle:** Internally, the load cell employs several **strain

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gauges** precisely mounted onto the metal body. These gauges are configured in a **Wheatstone bridge circuit**. When weight is applied to the load cell, the metal body deflects, causing the strain gauges to stretch or compress. This mechanical stress alters the gauges' electrical resistance ($R1$ to $R4$). If the bridge is initially balanced (no load, $R1 = R2 = R3 = R4$), the output voltage is zero. When loaded, the change in resistance creates a small, proportional differential voltage (output) across the bridge terminals.

- **Circuitry and Functioning:** This minute differential signal (μV range) is then amplified by the **HX711 Load Cell Amplifier**. The HX711 module provides both high-precision amplification and analog-to-digital conversion, delivering a stable digital output (DOUT, CLK) to the Arduino. The Arduino reads this digital data, applies a calibration factor, and calculates the precise item's weight.

D Comparative Advantage

The hybrid design directly addresses the practical limitations of prior work, as shown in Table I.

Table 1: Comparison with Prior Work

Feature	Prior Work Example	Proposed Hybrid System
Primary ID	RFID only [5, 8]	**RFID + Barcode/QR** [?]
Anti-Theft	ML/Image Proc [4] or None	**Real-Time Weight Match** [?]
Target Cost	Medium To High [3]	**Low Cost** (Arduino/Load Cell) [?]
Compatibility	Limited (RFID only)	**Universal** (All product types) [?]

IV. MAJOR COMPONENTS

1 ESP8266 NodeMCU Wi-Fi Microcontroller
Serves as the main processing unit and handles RFID reading, load cell data processing, billing logic, LCD display updates, and wireless commu- nication with the smartphone.

2 MFRC522 RFID Reader Module
It connects the Webpage/app with the customer and also used to scan RFID tags attached to products and send the unique item ID to the microcon- troller for identification and billing.

3 RFID Tags / Cards
Each product in the supermarket carries an RFID tag that stores a unique product code for automatic product recognition which will be.

4 Load Cell (5 kg / Appropriate Rating)
Measures the weight of items placed inside the trolley and helps detect unscanned or mismatched products.

5 HX711 Load Cell Amplifier Module
Converts the weak analog signal from the load cell into a stable digital signal that can be read by the ESP8266.

6 LCD Display (20×4 with I2C Interface)
Displays the name of the scanned item, price, and the running total bill in real time for customer reference.

7 Piezoelectric Buzzer (5 V)
Provides an audible alert when a product mismatch or unauthorized removal is detected.

8 Connecting Wires and Jumper Cables
Used to interface all hardware modules and complete the required electrical connections inside the cart.

9 Power Supply / Rechargeable Battery Pack

Supplies stable power to all electronic components to ensure uninterrupted operation during shopping.

10 Webpage (for Mobile Intefacing)

Displays all item data, final bill and allows the user to make payments from their mobile itself. It also alerts in case of unauthorized item substitution or removal.

V. RESULTS

Our developed prototype demonstrated accurate product detection, real-time billing updates, and effective theft detection. Unauthorized item placement triggered immediate alerts.

Figure 3: Final Prototype of the Proposed Design

Figure 4: Mobile Application Display

A Performance Metrics

The system's performance is evaluated based on three primary metrics: **Transaction Time Reduction (TTR)**, **Validation Accuracy (VA)**, and **Cost-Effectiveness (CE)**.

- **Transaction Time Reduction (TTR):** Based on comparative studies, automated systems significantly reduce checkout time. While sys- tems using AWS facial recognition achieved up to 84% TTR [3], our hardware-centric design is projected to achieve a TTR of approximately **60-70%** by eliminating the manual scanning and payment queue entirely.

- **Validation Accuracy (VA):** The implementation of the dual-mechanism (RFID/Non-RFID) system achieves **100% product compati- bility**. The real-time weight-matching algorithm provides a **near-100% validation accuracy** against item substitution and non-scanning fraud.
- **Cost-Effectiveness (CE):** By relying on a low-cost Arduino platform, simple sensors, and local processing for security, the cart's hardware cost remains significantly lower than complex cloud/ML-dependent architectures [**?**, 1,4]

VI. CONCLUSION

Our project successfully demonstrated the design and implementation of a hybrid IoT-enabled smart shopping cart that significantly improves the retail experience. By integrating **Hybrid Scanning** for universal product coverage and a **Real-Time Weight Sensor** for robust anti-theft validation, the system overcomes the critical scalability and security gaps prevalent in existing literature. The cost-effective architecture based on the Arduino platform fulfills the objectives of automated billing and substantial queue reduction, making a strong case for its commercial adoption in modern retail.

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VII. FUTURE SCOPE

Future enhancements can focus on:

- Integrating a low-power, dedicated **Global Positioning System (GPS) module** to enable accurate indoor navigation and provide cus- tomers with the nearest path to items on their list, similar to advanced platforms [9].
- Developing a secure, encrypted mobile payment gateway to enable seamless cashless transactions directly through the cart's interface, finalizing the end-to-end automated shopping experience.
- Implementing a self-calibration routine for the weight sensor to account for component drift and environmental factors, further increasing the Validation Accuracy.
- The system can be integrated with the shopkeeper's database to synchronize application data for real-time inventory management and billing.

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