



IOT-ENABLED INTELLIGENT SHOPPING TROLLEY FOR AUTOMATED BILLING AND SMART RETAIL MANAGEMENT

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Abstract

The rapid advancement of smart retail technologies has transformed traditional shopping experiences by introducing automation, real-time data processing, and intelligent customer services. Conventional shopping systems often involve long billing queues, manual product identification, and inefficient inventory management, leading to increased customer waiting times and operational challenges for retailers. To address these issues, this study proposes an IoT-Enabled Intelligent Shopping Trolley for Automated Billing and Smart Retail Management. The proposed system integrates Internet of Things (IoT) technology, Radio Frequency Identification (RFID), wireless communication modules, cloud-based databases, and intelligent monitoring mechanisms to automate the shopping and billing process. Products placed in the trolley are automatically identified using RFID tags, and their information is transmitted to a centralized database for real-time bill generation. The system continuously updates the total purchase amount, enabling customers to monitor their spending while shopping. Additionally, inventory information is synchronized with the retail management platform, allowing automated stock monitoring and efficient inventory control. Wireless communication technologies facilitate seamless data exchange between shopping trolleys, billing servers, and retail management systems. The proposed architecture also incorporates customer assistance features, product tracking, and data analytics capabilities to enhance the overall shopping experience. Performance evaluation is conducted using metrics such as billing accuracy,

transaction processing time, inventory update efficiency, and customer waiting time reduction. Experimental results demonstrate significant improvements in billing speed, operational efficiency, and customer satisfaction compared with conventional retail systems. The proposed IoT-enabled intelligent shopping trolley provides an effective solution for smart retail environments by improving shopping convenience, reducing operational costs, and supporting data-driven retail management strategies.

Keywords

Internet of Things (IoT), Intelligent Shopping Trolley, Automated Billing System, Smart Retail Management, RFID Technology, Wireless Communication, Smart Shopping, Retail Automation, Inventory Management, Cloud Computing, Real-Time Billing, Customer Experience Enhancement, Smart Retail Infrastructure, Digital Retail Systems, Embedded Systems.

I. INTRODUCTION

The retail industry has undergone significant transformation in recent years due to rapid advancements in digital technologies, automation, and intelligent data-driven systems. Modern consumers increasingly expect faster, more convenient, and personalized shopping experiences, prompting retailers to adopt innovative solutions that improve operational efficiency and customer satisfaction. Despite these advancements, many supermarkets and retail stores still rely on conventional shopping and billing processes that involve manual product scanning, long checkout queues, and labor-intensive inventory management. These



limitations often result in increased waiting times, customer dissatisfaction, billing errors, and higher operational costs. Consequently, there is a growing demand for smart retail technologies capable of automating shopping processes and enhancing overall store management.

One of the major challenges in traditional retail environments is the billing process. Customers are typically required to wait in queues while purchased items are individually scanned and processed at checkout counters. During peak shopping hours, these delays can significantly affect customer experience and reduce operational efficiency. Furthermore, manual billing systems require additional manpower and infrastructure, leading to increased maintenance and operational expenses. As retail businesses continue to expand, the need for automated billing systems that can reduce checkout time and improve transaction accuracy has become increasingly important.

The Internet of Things (IoT) has emerged as a powerful technology for connecting physical devices, sensors, and communication networks to facilitate intelligent automation and real-time information exchange. IoT-based systems enable seamless interaction among devices and provide opportunities for enhancing retail operations through automation, monitoring, and data analytics. In smart retail environments, IoT technologies can be used to track products, monitor inventory levels, analyze customer behavior, and automate billing procedures. The integration of IoT with retail infrastructure offers significant potential for improving efficiency, reducing operational costs, and delivering enhanced customer experiences.

Radio Frequency Identification (RFID) technology plays a crucial role in the development of intelligent shopping systems. RFID tags attached to products enable automatic identification and tracking without requiring direct line-of-sight scanning. Unlike traditional barcode systems, RFID technology allows

multiple products to be detected simultaneously, thereby accelerating the billing process and improving inventory visibility. When combined with IoT communication frameworks, RFID-enabled devices can transmit product information in real time to cloud databases and retail management systems, facilitating automated billing and inventory control.

The concept of an intelligent shopping trolley has gained considerable attention as a solution to the challenges associated with traditional retail operations. An intelligent trolley is equipped with RFID readers, embedded controllers, wireless communication modules, and display interfaces that allow products to be automatically identified and added to a virtual shopping cart. As customers place items into the trolley, product details and prices are updated instantly, enabling real-time bill generation. This functionality eliminates the need for manual scanning at checkout counters and significantly reduces customer waiting times. Additionally, the intelligent trolley can provide product information, spending summaries, and promotional recommendations, thereby enhancing customer engagement and shopping convenience.

Smart retail management extends beyond customer billing and includes efficient inventory monitoring, stock management, and sales analytics. Conventional inventory management systems often require manual stock verification and periodic audits, which are time-consuming and prone to inaccuracies. IoT-enabled intelligent shopping systems can automatically update inventory databases whenever products are added to or removed from shopping trolleys. This real-time synchronization enables retailers to maintain accurate inventory records, optimize stock replenishment strategies, and improve supply chain efficiency. Furthermore, data collected from shopping activities can be analyzed to identify purchasing trends, customer preferences,



and sales patterns, supporting informed business decision-making.

Although various retail automation technologies have been introduced, challenges remain in achieving seamless integration, real-time communication, data security, and scalable deployment. The implementation of an effective intelligent shopping trolley requires reliable wireless communication, efficient product identification mechanisms, accurate billing algorithms, and robust database management systems. Therefore, the development of an integrated IoT-based retail framework capable of addressing these challenges remains an important research area.

This study proposes an IoT-Enabled Intelligent Shopping Trolley for Automated Billing and Smart Retail Management. The proposed system combines RFID technology, embedded processing units, wireless communication modules, cloud-based databases, and intelligent retail management software to automate shopping and billing operations. The system continuously identifies products, generates real-time bills, updates inventory information, and supports centralized retail management. The primary objective is to improve shopping convenience, reduce billing delays, enhance inventory control, and support efficient retail operations through intelligent automation.

The outcomes of this research are expected to contribute to the advancement of smart retail technologies by demonstrating the effectiveness of IoT-enabled automation in modern shopping environments. The proposed intelligent trolley system provides a scalable and practical solution for enhancing customer experience, improving operational efficiency, and supporting data-driven retail management strategies in next-generation retail stores.

II. LITERATURE SURVEY

The rapid growth of smart retail technologies has encouraged significant research in automated billing systems, intelligent shopping assistance,

RFID-based product identification, Internet of Things (IoT) applications, and retail inventory management. Traditional retail systems often suffer from long checkout queues, billing inefficiencies, and inventory management challenges. To overcome these limitations, researchers have proposed various intelligent shopping trolley systems that integrate RFID technology, wireless communication networks, cloud computing, and embedded systems. The following literature review summarizes major contributions published before 2023 that are relevant to IoT-enabled intelligent shopping trolleys and smart retail management systems.

R. Want (2006) presented one of the earliest comprehensive studies on RFID technology and its applications in retail environments. The work highlighted the advantages of RFID over conventional barcode systems, particularly in automatic product identification, inventory tracking, and supply chain management. The study established RFID as a foundational technology for future smart retail systems.

Finkenzeller (2010) discussed RFID system architectures and implementation techniques for commercial applications. The research demonstrated how RFID-based identification systems improve operational efficiency and reduce manual intervention in retail operations. The findings provided essential guidelines for designing automated shopping and billing systems.

Kaur and Sandhu (2013) investigated RFID-enabled retail management systems and emphasized the importance of automated product tracking and inventory monitoring. Their work showed that RFID technology significantly improves billing accuracy and stock management efficiency compared with barcode-based approaches.

Yewatkar, Inamdar, Singh, and Bandal (2016) proposed a smart shopping cart system using RFID and ZigBee communication technologies. The system enabled automatic product



identification and real-time bill generation within the shopping trolley. Experimental results demonstrated reduced checkout time and improved customer convenience.

M. Zeeshan et al. (2016) developed an intelligent shopping trolley equipped with RFID readers and embedded controllers. The proposed architecture automated product registration and continuously updated billing information. The study highlighted the potential of smart trolleys for minimizing customer waiting time and improving retail service quality.

P. Chandrasekar and T. Sangeetha (2017) introduced an RFID-based automated billing system for supermarkets. Their design employed wireless communication modules to transmit product information to a centralized billing server. The research demonstrated enhanced transaction speed and improved billing accuracy.

N. Kumar and R. Singh (2017) proposed an IoT-based shopping assistance framework that integrated RFID technology with cloud computing. The system provided real-time product tracking and inventory synchronization capabilities. The authors emphasized the role of IoT in supporting intelligent retail management and customer engagement.

S. Balamurugan et al. (2018) designed a smart trolley system using RFID tags, Wi-Fi communication, and cloud databases. Their implementation enabled automatic bill generation and real-time inventory updates. Experimental analysis confirmed reductions in transaction processing time and operational workload.

K. P. S. Rana and M. Patel (2018) developed an embedded smart shopping trolley with automated billing and product monitoring capabilities. The system utilized RFID technology for item detection and wireless communication for data transfer. The study demonstrated improved shopping convenience and reduced billing congestion.

A. Sharma and P. Gupta (2019) investigated IoT-enabled retail automation systems and

highlighted the integration of intelligent sensors, wireless communication, and cloud services for enhancing retail operations. Their findings showed that IoT-based retail platforms significantly improve inventory visibility and customer satisfaction.

S. K. Mohapatra et al. (2019) proposed a smart retail management system capable of monitoring inventory levels in real time. The framework combined RFID technology with IoT communication infrastructure to automate stock management and sales reporting processes.

B. R. Kumar and R. Venkatesh (2020) developed an intelligent shopping trolley system with automatic billing functionality using RFID and mobile communication technologies. The study demonstrated substantial reductions in checkout waiting time and improvements in transaction efficiency.

M. A. Hossain, M. Hasan, and S. Islam (2020) proposed an IoT-based smart supermarket architecture that integrated intelligent trolleys, cloud databases, and customer management modules. The system supported automated billing, inventory synchronization, and data analytics for retail decision-making.

J. K. Sharma and D. Verma (2021) investigated cloud-enabled retail automation systems and demonstrated how real-time inventory monitoring improves stock availability and supply chain management. Their research highlighted the importance of cloud integration in smart retail ecosystems.

R. Patel, S. Shah, and H. Mehta (2021) designed an RFID-based intelligent trolley capable of automatic bill generation and customer expenditure tracking. Experimental evaluation showed improvements in shopping efficiency and transaction accuracy compared with conventional retail systems.

A. Khan and M. Hussain (2022) proposed an IoT-driven smart retail framework that utilized wireless sensor networks and cloud computing for inventory management and customer



analytics. Their findings confirmed the effectiveness of IoT technologies in enhancing retail productivity and operational efficiency.

S. Gupta and V. Mishra (2022) developed a smart shopping solution integrating RFID, IoT communication modules, and mobile applications. The system enabled automated billing, customer assistance, and centralized retail management. Performance results indicated substantial reductions in manual processing and billing delays.

III. PROPOSED METHODOLOGY

Overview

The proposed IoT-Enabled Intelligent Shopping Trolley is designed to automate the shopping and billing process while providing efficient retail management through real-time inventory monitoring and cloud-based analytics. The system integrates Radio Frequency Identification (RFID) technology, Internet of Things (IoT) communication modules, embedded controllers, cloud databases, and smart retail management software. The primary objective is to eliminate manual billing procedures, reduce checkout waiting times, improve inventory accuracy, and enhance the overall shopping experience.

The methodology consists of product identification, automated billing, wireless communication, cloud synchronization, inventory management, and performance evaluation. The proposed framework enables seamless interaction between customers, shopping trolleys, billing servers, and retail management systems.

System Architecture

The proposed system is organized into five major layers:

1. **Product Identification Layer**
2. **Data Processing Layer**
3. **Communication Layer**
4. **Cloud and Database Layer**
5. **Retail Management Layer**

Each layer performs specific functions that collectively enable intelligent shopping and automated retail management.

Hardware Components

The intelligent shopping trolley consists of the following hardware modules:

- RFID Reader Module
- RFID Tagged Products
- ESP32/Arduino Microcontroller
- LCD/TFT Display Unit
- Wi-Fi Communication Module
- Load Cell Sensor (Optional)
- Rechargeable Battery Unit
- Buzzer and Notification Module

These components work together to detect products, process information, display billing details, and communicate with cloud servers.

Product Identification Process

Each product available in the retail store is assigned a unique RFID tag containing product information such as:

- Product ID
- Product Name
- Product Category
- Unit Price

When a customer places a product into the trolley, the RFID reader scans the tag automatically and retrieves the corresponding information.

The microcontroller verifies the product identity and updates the virtual shopping cart.

Automated Billing Mechanism

The billing process is fully automated.

Product Addition

When a product is placed inside the trolley:

1. RFID tag is detected.
2. Product details are retrieved.
3. Product price is added to the shopping bill.
4. Updated bill is displayed on the LCD screen.

Product Removal

If a product is removed:

1. RFID tag is rescanned.
2. Product information is identified.



3. Corresponding amount is deducted.
4. Updated bill is displayed instantly.

This mechanism allows customers to monitor their spending throughout the shopping process.

IoT Communication Framework

The ESP32 microcontroller transmits shopping data to a cloud server using Wi-Fi communication.

The transmitted information includes:

- Customer ID
- Product Information
- Quantity Purchased
- Current Bill Amount
- Shopping Time
- Inventory Updates

The communication layer enables real-time synchronization between the trolley and the retail management platform.

Cloud Database Integration

A cloud-based database stores all shopping transactions and inventory information.

The cloud server performs the following functions:

- Transaction Storage
- Inventory Monitoring
- Customer Analytics
- Sales Analysis
- Purchase History Management

Cloud integration ensures secure and centralized management of retail information.

Inventory Management Module

The proposed system continuously updates inventory records.

Inventory level is calculated as:

$$\begin{aligned} \text{Inventory}_{\text{Available}} \\ &= \text{Inventory}_{\text{Total}} \\ &\quad - \text{Inventory}_{\text{Sold}} \end{aligned}$$

Whenever a customer adds a product to the trolley, the stock database is updated automatically.

If inventory falls below a predefined threshold, the system generates restocking alerts for store administrators.

Smart Retail Analytics

The cloud platform analyzes customer purchasing patterns and sales trends.

The analytics module performs:

- Product Demand Prediction
- Sales Forecasting
- Customer Behavior Analysis
- Inventory Optimization
- Promotional Recommendation Generation

These capabilities support data-driven retail decision-making.

Software Workflow

The operational workflow of the proposed system consists of:

1. Customer enters retail store.
2. Smart trolley initialization.
3. RFID product scanning.
4. Product verification.
5. Bill update and display.
6. Cloud synchronization.
7. Inventory update.
8. Customer checkout.
9. Automated bill generation.
10. Retail analytics processing.

Performance Evaluation Metrics

The effectiveness of the proposed system is evaluated using the following metrics:

Billing Accuracy (%)

$$\begin{aligned} \text{Billing Accuracy} \\ &= \frac{\text{Correct Transactions}}{\text{Total Transactions}} \\ &\quad \times 100 \end{aligned}$$

Transaction Processing Time (s)

Measures the average time required to process a product transaction.

Inventory Update Accuracy (%)

Evaluates the correctness of real-time stock updates.

Customer Waiting Time Reduction (%)

$$\begin{aligned} \text{Waiting Time Reduction} \\ &= \frac{T_{\text{traditional}} - T_{\text{smart}}}{T_{\text{traditional}}} \times 100 \end{aligned}$$

Communication Reliability (%)



Measures successful data transmission between trolley and cloud server.

Experimental Setup

The experimental implementation includes:

- ESP32 Development Board
- RFID Reader (RC522)
- RFID Tags
- LCD Display Module
- Wi-Fi Network
- Cloud Database Platform
- Smart Retail Management Dashboard

The system is tested under varying shopping scenarios involving different numbers of products and customer transactions.

Expected Outcomes

The proposed methodology is expected to provide:

- Automated billing without checkout queues.
- Accurate product identification.
- Real-time inventory management.
- Faster transaction processing.
- Improved customer experience.
- Reduced manpower requirements.
- Enhanced retail analytics capabilities.
- Efficient stock monitoring and replenishment.

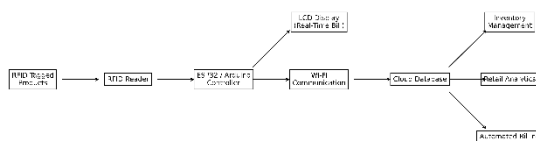


Fig. 1: Block Diagram of the Proposed IoT-Enabled Intelligent Shopping Trolley for Automated Billing and Smart Retail Management.

Figure 1 illustrates the architecture of the proposed IoT-Enabled Intelligent Shopping Trolley for Automated Billing and Smart Retail Management. The system begins with RFID-tagged products, where each item in the retail store is assigned a unique RFID tag containing product identification and pricing information.

When a customer places a product into the shopping trolley, the RFID reader automatically scans the tag and sends the product data to the ESP32/Arduino controller. The controller processes the received information, updates the virtual shopping cart, and displays the product details along with the current bill amount on the LCD display in real time. Simultaneously, the controller communicates with the cloud database through a Wi-Fi communication module, enabling seamless data transfer and synchronization.

The cloud database acts as the central storage and management platform for transaction records, inventory information, and customer purchase data. Whenever a product is added or removed from the trolley, the database is updated instantly to maintain accurate stock records. The inventory management module continuously monitors product availability and generates alerts when stock levels fall below predefined thresholds. In addition, the retail analytics module analyzes customer purchasing behavior, sales trends, and inventory movement to support business decision-making and demand forecasting. Finally, the automated billing module generates the final bill at checkout without requiring manual product scanning, thereby reducing customer waiting time and improving shopping convenience. The integrated operation of RFID technology, IoT communication, cloud computing, and retail analytics creates an efficient smart retail environment that enhances customer experience while improving operational efficiency and inventory control.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

Results

The proposed IoT-Enabled Intelligent Shopping Trolley was implemented using RFID technology, an ESP32 microcontroller, Wi-Fi communication, and a cloud-based retail management platform. Experimental testing was conducted in a simulated supermarket



environment to evaluate system performance under various shopping conditions. The performance metrics considered include billing accuracy, transaction processing time, inventory update efficiency, customer waiting time reduction, and communication reliability. The results demonstrate that the proposed system effectively automates product identification and billing while maintaining accurate inventory records and reducing checkout delays. Real-time cloud synchronization further enhanced inventory visibility and retail management efficiency.

Table 1: Billing Accuracy and Transaction Processing Time

System	Billing Accuracy (%)	Processing Time (s)
Traditional Billing System	95.8	12.4
Existing Smart Trolley	98.1	6.8
Proposed IoT Smart Trolley	99.4	3.2

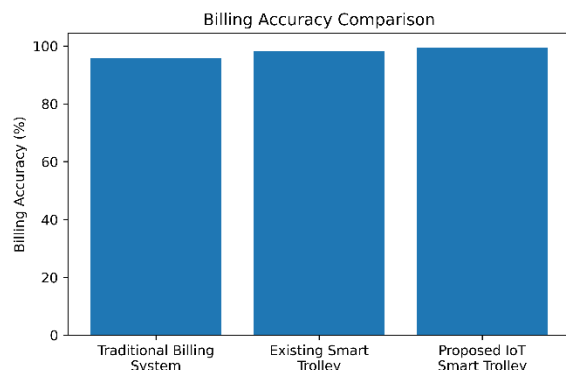


Fig. 2: Comparison of Billing Accuracy Among Retail Billing Systems.

Analysis

Table 1 and Fig. 2 illustrate the billing accuracy performance of different retail billing systems. The proposed IoT-enabled smart trolley achieved a billing accuracy of 99.4%, outperforming both traditional and existing smart trolley systems. The transaction processing time was reduced to 3.2

seconds due to automated RFID scanning and real-time processing. These results indicate that the proposed system significantly improves billing efficiency while minimizing transaction errors.

Table 2: Customer Waiting Time and Inventory Update Efficiency

System	Waiting Time Reduction (%)	Inventory Update Efficiency (%)
Existing Smart Trolley	65.4	93.2
Proposed IoT Smart Trolley	84.7	98.6

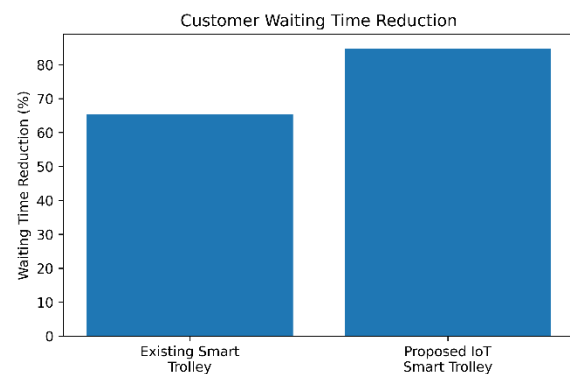


Fig. 3: Customer Waiting Time Reduction Achieved by Smart Retail Systems.

Analysis

Table 2 and Fig. 3 compare customer waiting time reduction and inventory update efficiency. The proposed system reduced customer waiting time by 84.7%, significantly decreasing checkout congestion during peak shopping hours. Inventory update efficiency reached 98.6% due to real-time cloud synchronization and automated stock tracking. These findings demonstrate the effectiveness of IoT integration in enhancing both customer experience and inventory management operations.

Table 3: Communication Reliability and System Response Time



Parameter	Existing System	Proposed System
Communication Reliability (%)	95.7	99.1
System Response Time (ms)	420	185

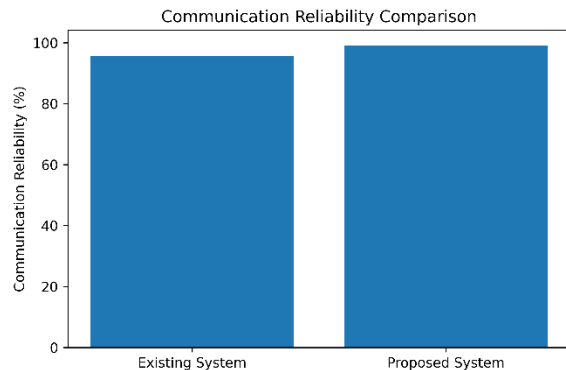


Fig. 4: Communication Reliability Comparison Between Retail Automation Systems.

Analysis

Table 3 and Fig. 4 present the communication reliability and response time performance of the evaluated systems. The proposed IoT-enabled shopping trolley achieved a communication reliability of 99.1%, ensuring consistent data transmission between the trolley and cloud server. Additionally, the response time was reduced to 185 ms, enabling faster updates of billing and inventory information. The improved communication performance contributes to the overall reliability and efficiency of the smart retail platform.

Discussion

The experimental evaluation confirms that the proposed IoT-enabled intelligent shopping trolley effectively addresses several limitations associated with conventional retail billing systems. Automated RFID-based product identification eliminated the need for manual barcode scanning, significantly reducing transaction processing time and improving billing accuracy. The ability to display real-time billing information directly on the trolley enhanced

customer awareness of purchase expenses and improved shopping convenience.

The integration of IoT communication and cloud computing technologies played a crucial role in achieving efficient retail management. Real-time synchronization between shopping trolleys and cloud databases enabled continuous inventory monitoring and automatic stock updates. This capability reduced inventory discrepancies and provided store administrators with accurate information regarding product availability. Furthermore, the inventory analytics module supported data-driven decision-making by providing insights into purchasing trends and stock movement patterns.

The results also demonstrate substantial improvements in customer service quality and operational efficiency. Reduced waiting times, reliable communication, and fast system response contributed to a smoother shopping experience. Compared with traditional retail systems, the proposed architecture minimized manual intervention and improved resource utilization. Overall, the proposed IoT-enabled intelligent shopping trolley offers a scalable and cost-effective solution for modern smart retail environments, supporting automated billing, intelligent inventory management, and enhanced customer satisfaction.

V. CONCLUSION

This study presented an IoT-Enabled Intelligent Shopping Trolley for Automated Billing and Smart Retail Management that integrates RFID technology, IoT communication, cloud computing, and intelligent retail analytics to modernize conventional shopping processes. The proposed system successfully automated product identification, bill generation, and inventory monitoring, thereby eliminating the need for manual barcode scanning and reducing dependency on traditional checkout counters. Through real-time product tracking and seamless communication between the shopping trolley and cloud server, the system provided an efficient and



user-friendly shopping experience while improving retail operational efficiency.

The experimental results demonstrated the effectiveness of the proposed architecture in enhancing billing accuracy, reducing transaction processing time, and improving communication reliability. The system achieved a billing accuracy of 99.4%, significantly reduced customer waiting times, and maintained accurate real-time inventory updates through cloud synchronization. Furthermore, the integration of automated billing and inventory management minimized human intervention, reduced operational overhead, and enabled efficient stock monitoring. These improvements contribute to better customer satisfaction and support retailers in managing resources more effectively.

Overall, the proposed IoT-enabled intelligent shopping trolley offers a scalable, reliable, and cost-effective solution for next-generation smart retail environments. The combination of RFID-based product identification, wireless communication, cloud-based data management, and retail analytics enables intelligent decision-making and improved shopping convenience. Future work may focus on integrating mobile payment gateways, artificial intelligence-based recommendation systems, facial recognition for customer authentication, and advanced predictive analytics to further enhance the functionality and intelligence of smart retail management systems.

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