



# Design and development of an IoT-based smart trolley with budget-limiting features to reduce queues in supermarkets

Achmad Zuchriadi<sup>1</sup>, Budhi Martana<sup>2</sup>, Fajar Rahayu<sup>3</sup>, Sigit Pradana<sup>4</sup>

<sup>1,2,3,4</sup>Faculty of Engineering, Universitas Pembangunan Nasional Veteran Jakarta, Indonesia

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## ABSTRACT

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This study presents the design and implementation of a smart shopping trolley system based on Internet of Things (IoT) technology, aimed at improving retail efficiency and customer control. The system integrates an ESP32 microcontroller, RFID reader, LCD display, keypad, and buzzer to monitor total purchases in real time and alert users when a predefined budget is exceeded. Through a design and development methodology, the prototype was tested using 25 products and 10 scenarios. Results showed 100% accuracy in item detection and instant budget alert response. This research addresses a key gap in previous smart trolley systems by incorporating dynamic budget control and user-defined notifications. The system offers strong potential for further integration into real retail environments and serves as a foundation for future smart retail innovations..

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### Corresponding Author:

Achmad Zuchriadi,  
Faculty of Engineering,  
Universitas Pembangunan Nasional Veteran Jakarta,  
Jl. RS. Fatmawati, Pondok Labu, Jakarta Selatan, DKI Jakarta, 12450, Indonesia  
Email: [Achmad.zp@upnvj.ac.id](mailto:Achmad.zp@upnvj.ac.id)

## 1. INTRODUCTION

The digital transformation of the modern retail sector has significantly reshaped how consumers interact with products and services in shopping environments (Palmié et al., 2022; Roe et al., 2022; Salume et al., 2021). The advancement of technologies such as the Internet of Things (IoT), Radio Frequency Identification (RFID), and sensor-based information systems has opened substantial opportunities to enhance both the efficiency and the overall customer experience during shopping activities (Bita et al., 2021; Popi Wulandari et al., 2022). In Indonesia, following the relaxation of restrictions under the Community Activity Restrictions (PPKM), consumer activity in supermarkets and hypermarkets has surged (Idah Kusuma Dewi, 2023). However, this resurgence has also revived a persistent issue: long queues at cashier counters, which negatively impact convenience, health, and transactional efficiency (Murnawan, 2023; Purwantono et al., 2021).

Several key factors contribute to the formation of checkout queues, including the limited number of cashiers, the time-consuming process of manually scanning each item, and the lack of real-time information regarding the total value of purchases before arriving at the cashier (Antczak et al., 2020; Martinus et al., 2021). These issues may

lead to decreased customer satisfaction, increased workload for cashiers, and unnecessary delays that consume valuable time which could otherwise be utilized productively (Bello-Salau et al., 2021). Furthermore, mismatches between customers' available funds and the actual cost of their shopping frequently result in item removals or additions at the checkout line, ultimately slowing down the payment process (Popi Wulandari et al., 2022). This indicates that existing solutions are still unable to fully address customer needs for efficiency and financial control during shopping.

As consumers increasingly demand faster, more accurate, and informative service experiences, the implementation of smart technological solutions in retail settings has become more urgent. Numerous studies have proposed the integration of RFID and IoT technologies to streamline the checkout process, improve inventory visibility, and provide real-time shopping information to customers (Deepa et al., 2021; Muralidharan et al., 2021a; Sutagundar et al., 2018). However, most of these systems remain limited to automated item scanning and lack the functionality to dynamically present the cumulative cost of purchases or to issue alerts when a predefined budget threshold is exceeded (Dhivyaa et al., 2021; Gunawan et al., 2023). In other words, prior research has primarily emphasized automation, while overlooking the equally important aspect of real-time budget control.

Moreover, existing approaches have yet to incorporate active budget control mechanisms into the customer shopping process (Gunawan et al., 2019; Hanooja et al., 2020; Muralidharan et al., 2021b; Shankar et al., 2021). The absence of such features represents a significant research gap, as effective and transparent budget management is crucial for delivering a satisfying and sustainable shopping experience. There is, therefore, a growing need for shopping systems that not only automate transaction logging but also feature real-time budget monitoring and immediate notifications when expenditures surpass the set financial limit.

Addressing this gap, the present study proposes the design of an integrated IoT-based smart shopping system that is capable of displaying real-time total purchase values while simultaneously delivering automatic alerts when a user-defined budget is exceeded. This system is expected to improve transactional efficiency, reduce waiting time, and provide consumers with greater control over their spending behavior.

The primary contribution of this research lies in introducing a novel approach to retail information systems by integrating budgeting, digital notifications, and real-time transaction visibility. By doing so, this study not only responds to technological advancements in retail but also emphasizes user empowerment, thereby offering both empirical and practical implications for the development of next-generation smart cashier systems.

## 2. RESEARCH METHOD

This study adopts a system engineering design research approach, focusing on the development of an IoT-based shopping information system capable of detecting total purchases in real-time and providing alerts when spending exceeds a predefined budget. This approach was chosen because system engineering design emphasizes a structured and iterative process of integrating hardware and software, making it particularly suitable for applied technology development in real-world retail contexts. Compared to purely experimental or survey-based methods, it allows the prototype to be systematically designed, implemented, and validated step by step, ensuring both technical feasibility and practical relevance. The research methodology follows a systematic sequence that includes literature review, system requirements analysis, system design, hardware and software integration, and functional testing and evaluation.

### 2.1 Research Design

This research falls under the category of applied research by integrating technological components such as RFID, ESP32 microcontroller, and LCD display modules into a practical system that can be implemented within real-world retail shopping processes. The primary objective of this approach is to provide an information technology-based solution aimed at reducing checkout waiting time and enhancing customer control over their shopping budget.

## 2.2 Literature Study and Requirements Analysis

The initial phase involved a comprehensive literature review of scholarly references published within the past five years, covering both accredited national journals and reputable international journals. The references were used to identify the limitations of conventional shopping systems, analyze technology-based solutions involving RFID and IoT in the retail sector, and formulate system requirements and design parameters for an effective and efficient IoT-based shopping system. Requirements analysis employed a function-based decomposition approach, covering specifications for inputs, processes, and outputs of the smart shopping information system.

## 2.3 System Design

The system was designed on two levels: hardware and software. The hardware components include the ESP32 microcontroller with Wi-Fi and Bluetooth connectivity, an RFID reader, RFID stickers for product identification, a 16x2 LCD as the user interface, a buzzer for notifications, and a keypad for initial budget input from the customer. The software was developed using the Arduino IDE and includes algorithms for processing shopping data and monitoring budget limits. The system flow involves initialization and budget input, RFID scanning when items are placed in the cart, automatic addition of item prices, detection of item removal, cumulative price calculation, and alert notifications when the spending exceeds the predefined budget.

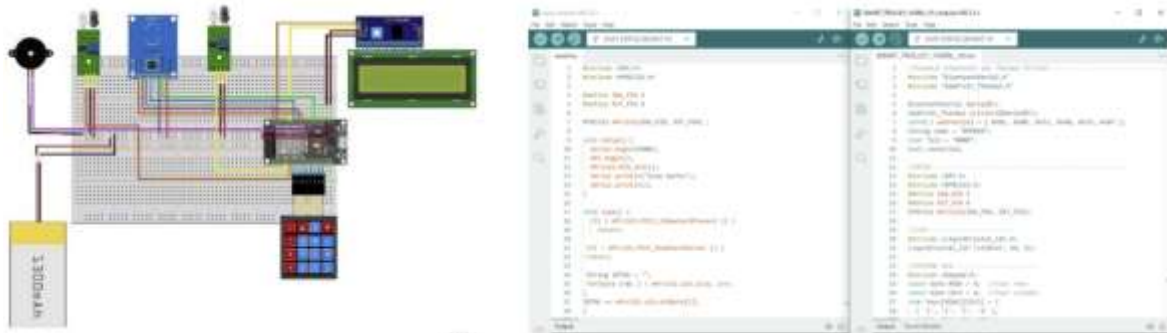


Figure 1 Hardware and software design

## 2.4 System Implementation and Integration

All components were assembled into a prototype using a standard shopping basket to simulate a real trolley. Hardware and software integration was carried out iteratively using a bottom-up integration approach. Preliminary testing was conducted in a laboratory setting to verify the basic functions such as RFID reading, price summation, budget input handling, and alert notifications, ensuring that they operated according to design specifications.

## 2.5 System Testing and Evaluation

System testing was performed using the black-box testing method to evaluate the accuracy and reliability of key functions. Test scenarios involved assessing the RFID reading accuracy across 25 different products, examining system response to repeated scanning (stability), validating the item removal function (deducting values from the total

cost), and observing system behavior when the budget was exceeded, including the correctness of generated alerts. The evaluation was conducted quantitatively by scanning data with ten repetitions per product. System performance was measured based on the success rate of RFID tag recognition, consistency of alert notifications upon budget violation, and accuracy in total price calculation.



Figure 2 System Testing

### 3. RESULTS AND DISCUSSIONS

This section presents the outcomes of the system development and testing phases, followed by a comprehensive discussion that highlights the scientific contribution and positions the present study within the context of existing literature. The results are organized into sub-sections to ensure clarity and alignment with the research objectives.

#### 3.1 System Performance Results

The smart shopping trolley prototype was tested using 25 different RFID-tagged products and evaluated across 10 simulated shopping scenarios. The system was able to detect RFID tags with a 100% success rate, and the total shopping value was displayed in real time on the 16x2 LCD. When users input a predefined budget via the keypad, the system accurately monitored cumulative spending and triggered both visual and auditory alerts as soon as the budget threshold was surpassed. These functionalities were consistent across all scenarios, and no errors or miscalculations were recorded.

The item removal feature, which was activated by re-scanning an item already recorded, functioned as intended. The total cost was immediately updated to reflect the deduction, and the system maintained stability throughout repeated interactions. System response time to user actions, including RFID scans and keypad inputs, was recorded to be under one second on average.

Table 1 RFID Tag Detection

No	Item	Price	Attemp										
			1	2	3	4	5	6	7	8	9	10	
1	Item-1	3600	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
2	Item-2	3500	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
3	Item-3	10.000	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
4	Item-4	4.700	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
5	Item-5	4.900	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
6	Item-6	5.600	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
7	Item-7	10.000	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
8	Item-8	18.000	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok

9	Item-9	4.000	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
10	Item-10	96.000	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
11	Item-11	9.000	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
12	Item-12	11.700	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
13	Item-13	20.000	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
14	Item-14	9.000	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
15	Item-15	18.500	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
16	Item-16	5.000	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
17	Item-17	33.000	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
18	Item-18	29.300	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
19	Item-19	4.200	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
20	Item-20	40.000	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
21	Item-21	16.000	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
22	Item-22	10.000	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
23	Item-23	15.000	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
24	Item-24	9.300	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
25	Item-25	33900	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok

Table 2 Price Accumulation, Budget Threshold Alert and Item Removal Function Test

No	Attemp	Input Budget	Price Accumulation	Budget Threshold Alert Trigger	Item Deduction	Re-calculate Total Price
1	Attempt-1	ok	ok	ok	ok	ok
2	Attempt-2	ok	ok	ok	ok	ok
3	Attempt-3	ok	ok	ok	ok	ok
4	Attempt-4	ok	ok	ok	ok	ok
5	Attempt-5	ok	ok	ok	ok	ok

A summary of system performance is shown in Table 3.

Table 3 Summary of system performance

No	Function	Accuracy
1	RFID Tag Detection	100%
2	Price Accumulation	100%
3	Budget Threshold Alert Trigger	100%
4	Item Removal Function	100%

### 3.2 Research Gap Analysis and Comparative Discussion

While numerous studies have proposed smart shopping trolleys with automated checkout capabilities, most have primarily focused on accelerating the payment process and reducing queue time, such as those developed by (Karjol et al., 2018; Kowshika et al., 2021; Yeshwant Raj et al., 2018). These systems utilized RFID for product detection and embedded microcontrollers for cost calculation, but lacked integrated features for real-time budget management.

Moreover, previous works, including (Das et al., 2020)), emphasized automated billing and digital payment integration but did not include user-defined budget limitations or alerts, which are essential for consumers concerned with financial control. (Thennavan et al., 2025)also noted that despite technological advances, the absence of spending control features in smart retail systems represents a significant gap in delivering customer satisfaction.

This research directly addresses this gap by introducing a budget-limiting mechanism that allows users to define their maximum spending before shopping, monitor it dynamically, and receive alerts when the limit is exceeded. This capability enhances not only the functionality but also the practical value of the system, especially in contexts where budget-conscious behavior is common, such as in Indonesian retail markets post-COVID-19.

### 3.3 Scientific Contribution and Implications

The scientific contribution of this study lies in the integration of real-time budget monitoring into an IoT-based smart trolley system, which extends the traditional scope of smart cart research. Unlike prior systems that focused solely on convenience or checkout

automation, this research contributes a novel user-centered budgeting feature, combining RFID-based item tracking with embedded intelligence to support financial awareness during shopping.

From a practical standpoint, the system improves consumer control over expenses, minimizes checkout surprises, and reduces decision-making delays at the cashier. These enhancements are aligned with current trends in digital transformation in retail, especially in promoting self-service and cashierless systems. Furthermore, the integration of ESP32 and open-source tools provides a low-cost, scalable solution that can be adopted by small to medium retail businesses in developing countries.

### 3.4 Limitations and Future Work

Although the system performed well in lab conditions, it has yet to be validated in actual retail environments, where factors such as environmental noise, shopper behavior, and Wi-Fi interference may impact performance. Future work should involve pilot testing in supermarkets, adding mobile application connectivity, and incorporating machine learning to recommend cost-effective product bundles based on budget constraints.

## 4. CONCLUSION

This study successfully achieved its objective of developing a smart trolley system with real-time spending monitoring and budget control, enhancing shopping efficiency and promoting spending awareness. By introducing user-defined financial control—absent in prior works—the system bridges a critical gap in smart retail technology, shifting the focus from mere automation to user empowerment. In addition, this research provides practical implications for the Indonesian retail sector by offering solutions to reduce queues and improve customer satisfaction, while also contributing theoretically to the development of user-centered IoT systems that integrate financial awareness into shopping activities. Future studies should include field trials using real transaction data and explore integration with modern cashier systems to validate robustness and strengthen scalability for commercial adoption.

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