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Enhanced Shopping Experiences: The Role of RFID Technology in Smart Carts

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Abstract

Over the past decade, the Internet has revolutionized the way individuals shop, with the rise of e-Commerce allowing consumers to buy products online through platforms like Amazon and Flipkart. However, traditional physical markets are still growing and offer a personal shopping experience. This project aims to create a Smart Shopping Cart that can be used in supermarkets to address common customer issues such as waiting in long queues for billing and overspending. This technology reduces the burden on cashiers by automatically calculating the total cost of the items in the cart. The Smart Cart provides a fast and efficient service, reducing congestion at the checkout counter and saving time and effort during the accounting process. The items in the cart are scanned for price and barcode details and the cost of each item is calculated and sent to an Arduino device. In traditional Indian markets, customers place items in a cart and then stand in a queue for billing, but this Smart Cart eliminates the need for this step.

Keywords: RFID Tag; LCD, RFID Reader; Barcode Scanner; WiFi; Central Charging Unit

1 Introduction

Humans have consistently invented new technologies to satisfy their needs and requirements since the dawn of mankind. The primary motive behind the development of new inventions is to gain more independence, resulting in the improvement of tasks and making routine ones simpler and faster [1]. One everyday activity that requires significant effort is shopping. A store is a place where individuals acquire their daily necessities, ranging from basic items like food and garments to electronic gadgets [2]. Traditionally, customers choose their desired items, place them in their shopping baskets or trolleys, and then face prolonged queues at the checkout counters for billing. The payment process at these counters is often frustrating and time-consuming, leading to significant congestion and wait times [3]. According to research, people spend approximately 1.4 hours shopping in stores, and many will leave if the lines are too long [4]. The proposed smart basket system aims to enhance the efficiency of in-store shopping. This innovation involves a handbasket equipped with RFID labels to track the items in the cart, along with an RFID reader and an LCD screen. This setup enables customers to view the cost of each item and the total cost of all items in the cart, thereby saving time for customers and reducing the staffing needs in shopping complexes, making the shopping experience more convenient and efficient. RFID (Radio-Frequency Identification) is an emerging technology that has recently garnered significant attention in research communities due to its advantages over existing systems. RFID technology facilitates the exchange of information between labels and readers without the need for a direct line of sight, covering distances of several meters, depending on the type of tag used.

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In RFID systems, data communication is conducted via radio waves, and the labels are consistently scanned or collected. The technology involves storing information on a device akin to a smart card, offering numerous advantages over other commonly used identification systems. The key strengths of RFID technology include its ability to rapidly and accurately read data from tags without requiring physical contact or line-of-sight positioning, which significantly enhances efficiency in various applications such as inventory management, asset tracking, and smart shopping systems [5–8]. The integration of RFID technology in shopping carts can streamline the shopping experience by automatically identifying and tallying items as customers add them to their carts, mitigating the need for manual scanning at checkout counters. This advancement not only expedites the billing process but also contributes to reducing queue times and improving overall customer satisfaction in retail environments. Figure 1 schematically represents the working of RFID technology.

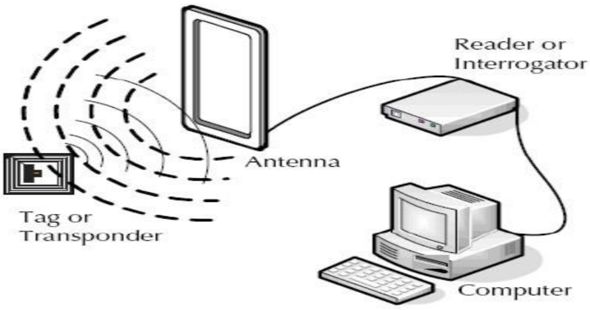


Figure 1: Working of RFID system

The primary objective of this project is to develop an enhanced shopping experience by integrating RFID technology into a shopping cart. The focus is on embedding RFID-based strategies within the cart's functionality, employing RFID cards to secure product acquisition within shopping complexes. When an item is placed in the cart, its cost is promptly displayed on the LCD, contributing to the cumulative total. Conversely, the removal of an item results in an immediate deduction from the total amount. The central aim is to establish a shopping environment that is more user-friendly, streamlining and expediting the shopping process compared to the current paradigm. This innovation is expected to significantly reduce waiting times at billing counters, offering considerable time-saving benefits to customers.

2 Related Work

2.1 Analysis of RFID from printed reviews

An examination delving into the benefits of tagging items with RFID labels for routine operations and business value in high-quality retail settings reveals significant advantages. The findings indicated that the overall stock accuracy improved by an additional 27% when using RFID technology [9]. Several studies [10, 11, 6] have also compared the efficiency of managing inventory with RFID tags versus traditional barcode tag readers. It was observed that with RFID, the process of assessing an equivalent number of articles required only two hours, whereas using a conventional barcode scanner necessitated fifty-three hours. This dramatic reduction in time highlights the superiority of RFID in terms of operational efficiency. The ability of RFID to read multiple tags simultaneously without direct line-of-sight [12] contributes to this efficiency, making it an ideal solution for fast-paced retail environments. Implementing RFID not only enhances inventory management but also translates into better customer service by reducing the likelihood of stockouts and inaccuracies in inventory records [13, 14, 9]. Consequently, RFID technology represents a significant advancement over traditional barcode systems, offering tangible benefits in terms of time savings and improved accuracy in retail settings.

2.1.1 RFID Usage Challenges

While Radio-Frequency Identification (RFID) technology offers notable advantages in terms of speed and efficiency, it cannot entirely replace traditional barcode technology due to its comparatively higher cost and lower precision [15]. Nevertheless, prominent companies in various sectors such as CVS, Tesco, Prada, Benetton, Walmart, and Procter & Gamble are actively adopting and investigating the impact of RFID technology on their operations. The potential for RFID adoption extends beyond these industries, but it is essential to comprehensively understand its development and various facets to mitigate potential challenges. The effective implementation of an RFID system requires considerable energy and commitment, as this technology faces various implementation challenges. The primary challenges include issues related to scalability, global integration, regulatory compliance, and cost considerations.

For instance, each shopping cart needs to be outfitted with a device that contains an RFID sensor. Furthermore, every product within the shopping center must be tagged with RFID labels [3]. As customers place items into their carts, the RFID sensor identifies the corresponding data, and the cost of each product is recorded in the storage unit of the cart. As additional items are added, their prices are cumulatively calculated to determine the total amount. This entire computation process takes place within the cart itself. Details about the items, including their prices, are displayed on an LCD screen attached to the cart. As customers near the payment center, comprehensive invoice information is transmitted to a personal computer through encrypted radiofrequency modules. This step ensures that the billing process is seamless and efficient. However, the widespread implementation of this system poses significant logistical and financial challenges. Ensuring that all products are accurately tagged and that each cart is properly equipped and maintained requires substantial investment and coordination [16]. Additionally, the system must be designed to handle the vast quantity of data generated and to integrate smoothly with existing retail management systems. Despite these challenges, the potential benefits of RFID in enhancing the shopping experience and streamlining retail operations make it a promising area for further development and innovation.

2.2 Comparative Analysis of Existing Model

The existing smart cart models employ various technologies and offer a range of features, advantages, and disadvantages as summarized in Table 1.

Table 1: Comparison analysis of existing models

Smart Cart Model	**RFID Technology Used**	**Features**	**Advantage**	**Disadvantages**
Amazon Dash [17–19] Cart	Ultra-wideband (UWB) and RFID	Automatically detects products and adds them to the cart, checkout-free experience, built-in scale for measuring weight.	Removes the need for cashiers and conventional checkout lines, provides real-time information about the total cost of items purchased, and saves time.	Limited to Amazon Fresh grocery stores only, UWB technology has a limited range.
Kroger Smart Cart [20? –23]	RFID	Scans and weighs items automatically, allows shoppers to pay directly from the cart, and has a built-in touchscreen for adding or removing items.	Saves time, removes the need for cashiers and conventional checkout lines, and allows shoppers to keep track of the total cost of their items.	Currently available in only one location in the U.S.
Wheelys Moby Mart [24–27]	RFID	A self-driving convenience store that uses RFID to track items taken by shoppers, and automatically charges their account when they leave the store.	Convenient and accessible, removes the need for cashiers and conventional checkout lines and provides real-time inventory management.	Limited to certain locations and may not work for all types of products.
Intelligent Cart [28–30]	RFID	Automatically scans and weighs items, tracks a shopper's location in the store, and provides recommendations based on their shopping history.	Saves time, provides personalized recommendations, and eliminates the need for cashiers.	Limited availability and may not work for all types of products.
Scandit Smart Grocery Cart [31, 32]	RFID	Scans and weighs items, allows shoppers to pay directly from the cart, and provides real-time information about the total cost of items purchased.	Saves time, removes the need for cashiers and conventional checkout lines, and provides real-time inventory management.	Limited availability and may not work for all types of products.

Table 1 presents the comparison of existing hardware with a few features matching the proposed model. It is important to note that such hardware does not exist at the national level, and at the international level, the cost of the product is too high with fewer features as compared to the proposed model. The proposed model offers a lot of additional features with very less cost which will be affordable for many retailers. A reseach works have demnstrated smart shopping cart leveraging RFID technology for product identification and an automated billing system for calculating total item costs within the cart [33, 34]. The framework generally employs an Arduino microcontroller to handle data from the RFID reader and present the cumulative cost on an LCD display. Empirical tests utilizing RFID reader and tags demonstrated high accuracy and efficiency. Yet another research introduced a smart shopping cart harnessed with RFID technology for product recognition and an automatic billing system for computing total cart costs. The setup integrates an RFID reader, microcontroller, LCD display, and even includes a barcode scanner to enhance product identification. Thorough evaluation involving RFID tags and barcode scanning affirmed its proficiency in product identification and cost computation [35]. Another research work focused on developing an automated billing system. This system leverages RFID (Radio-Frequency Identification) technology and cloud computing to streamline the billing process. Their work aims to enhance the efficiency and accuracy of billing systems, particularly in retail environments, by automating the identification and calculation of product prices. The integration of RFID with cloud computing in their proposed system suggests a modern approach to handling transactions, aiming to reduce manual effort and errors associated with traditional billing methods [36]. In these studies, researchers have innovatively harnessed RFID technology in smart shopping cart systems, with each approach contributing novel insights and benefits to enhance the shopping experience.

2.3 Research Gaps

Despite the technological advancements in RFID technology, there is a critical need to revitalize the structural framework of this technology to ensure scalability in line with evolving requirements. Current literature has significantly focused on RFID anti-collision protocols to enhance system performance. However, empirical studies evaluating the benefits of the Cipher Isolation approach remain limited [37]. A substantial body of research has been dedicated to assessing the performance of RFID systems, but there are still challenging issues that need addressing to improve the overall functionality of these systems. One notable gap in the literature is the limited exploration of fault detection and uncertainty handling in RFID data. Addressing real-world uncertainties associated with RFID data is essential for achieving more semantically robust objectives for broader applications. Moreover, as indicated in the initial part of this literature review, the volume and speed of data generation in RFID systems are set to outpace the capabilities of the current technological infrastructure. It is therefore crucial not only to propose designs that can manage advanced RFID data but also to address existing challenges in RFID systems, taking into account real-world vulnerabilities. This pressing need highlights the importance of pushing this area of concern to the forefront and striving for comprehensive advancements in RFID technology.

3 Methods

3.1 Proposed Methodology

The proposed framework detailed in this thesis is divided into two main sections, as illustrated in Figures 2 and 3. These figures present the block diagrams of the envisioned system, showcasing how the RFID reader interfaces with an Arduino Nano, which in turn connects to both an LCD and a WiFi module, thus facilitating the transmission of billing details to the central billing unit. Within the transmitter section, as depicted in Figure 2, the reader detects RFID tags on the products and conveys the acquired data to the Arduino Nano. The Arduino Nano then compares this data with its internal database and displays the result on the connected LCD screen. This part of the system is responsible for providing immediate feedback to the consumer regarding the cost of individual items as well as the running total of their shopping cart. The WiFi transmitter component is tasked with sending the data showcased on the LCD screen to the central billing unit. This information is captured by a WiFi receiver at the central billing unit. The central billing unit, as shown in Figure 3, then processes the received data to generate a printed record of the transaction [38]. This methodology underscores the seamless integration of different components to create a holistic system that enhances the shopping experience by automating the billing process and minimizing the time consumers spend at the checkout counter.

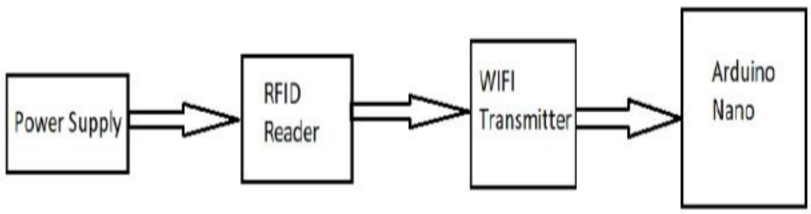


Figure 2: Block diagram of the transmitter section of the proposed system.

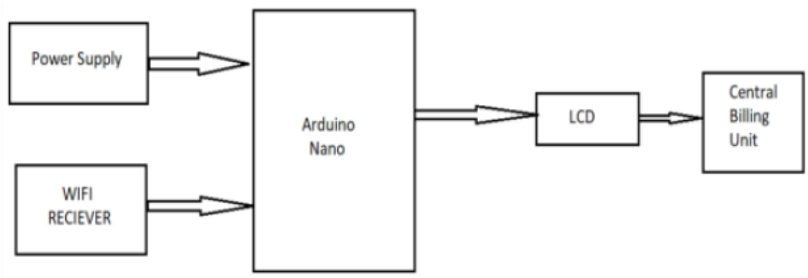


Figure 3: Block diagram of the receiver section of the proposed system.

4 System Design

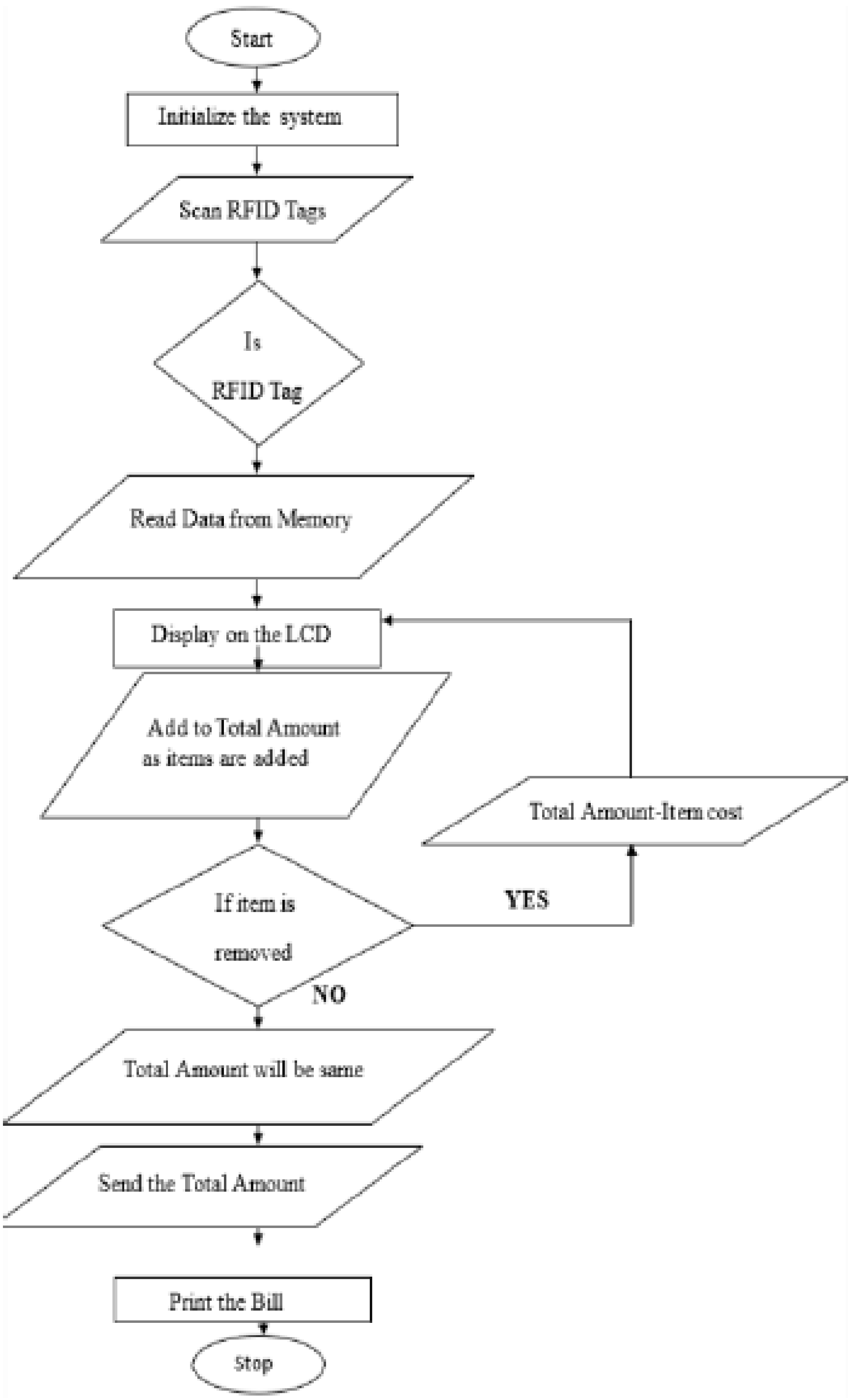


Figure 4: Flowchart illustrating the operation of the proposed system.

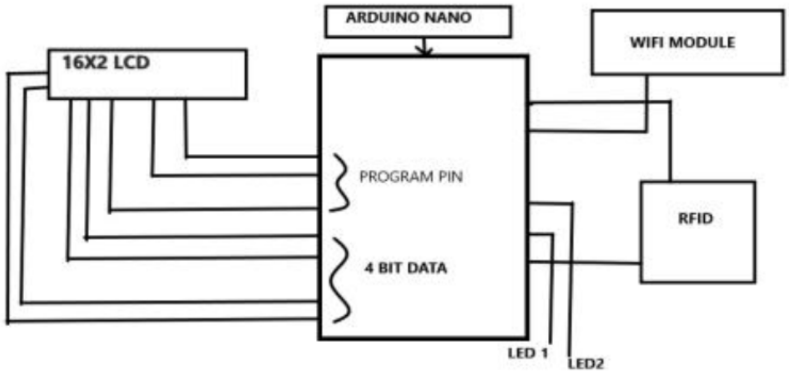


Figure 5: Schematic design of the proposed system.

Figure 4 presents the flowchart that illustrates the working mechanism of the proposed system. Figure 5 details the schematic design of the system. The system's hardware setup is as follows: The Arduino Nano is powered by a 5V supply via USB from a computer. The LCD's input power pins are connected in the following manner: Pin 1 (GND) to ground, Pin 2 (VCC) to a 5V power source, and Pin 3 (VEE) to a 1k ohm resistor. The data command pins, Pin 4 (RS) and Pin 6 (EN), are connected to Arduino's digital pins D-2 and D-3, respectively. The data pins, D4 to D7, are connected to Arduino's digital pins D-4 to D-7 respectively. For the RFID module, it is supplied with 3.3V power through a 5V voltage regulator, with its communication pins, RST, SDA, MOSI, MISO, and SCK, connected to Arduino's digital pins D-9 to D-13 respectively. The Wi-Fi module's RX and TX pins are interfaced with the corresponding RX and TX pins on the Arduino, ensuring data transmission to the central billing system. This configuration is intended to ensure seamless connectivity and functionality among the various components, leading to efficient operation of the overall system.

4.1 System Components

4.1.1 Arduino NANO

The Arduino Nano is a small, complete, and breadboard-friendly microcontroller board based on the ATmega328 [39]. It is devoid of a DC power jack and is instead powered via a Mini B USB cable. The Nano, developed by Arduino, is designed for convenience and ease of integration into various projects, including those that are space-constrained.

4.1.2 RFID Module

The RFID module employed in this project is based on the EM18 RFID Module. It provides a convenient and time-saving means of reading data through microcontrollers [40]. The module requires a simple serial connection for interface and is compatible with other boards through +5V and GND header wires. It includes an onboard 5V voltage regulator, allowing for a 9-15V DC adapter power supply. The board is equipped with a red LED to indicate power status and a green LED with buzzer for card or tag detection. A selection jumper is available for switching between output formats, including a Weigand 26 O/P. It is important to note that selecting a different mode will change the protocol, affecting the ability to read data through standard serial protocols. The following are the features:

- The RFID module is an economical option for reading passive RFID transponder tags. It operates at a frequency of 125 kHz with a 9600 bps serial interface and is capable of reading EM 4100 compatible transponders [40].
- The module offers a read distance of up to 6-10 cm for cards and 5 cm for key tags, featuring onboard LED and buzzer indications.
- It provides output through both serial UART from pin headers (TTL CMOS) and RS-232 (DB9), facilitating easy interfacing with a range of devices.

4.2 ESP 8266

The ESP8266 is a low-cost Wi-Fi microchip with full TCP/IP stack and microcontroller capability, developed by Espressif Systems [41]. Since its release in 2014, it has gained immense popularity in the IoT community for its efficiency, small size, and integrated Wi-Fi functionalities. The ESP8266 is an excellent choice for IoT projects due to its versatility, power, and cost-effectiveness.

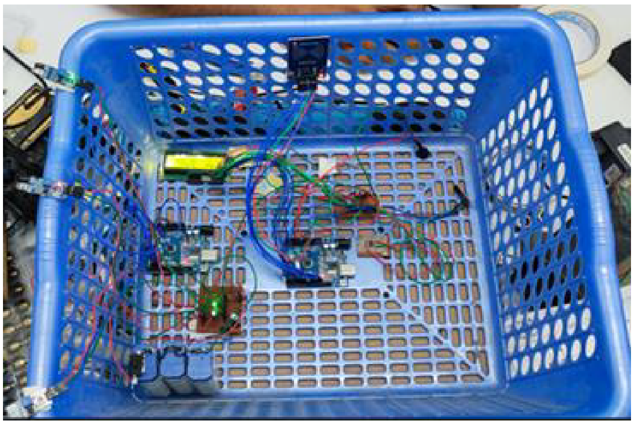
4.3 Software Used

Remote XY is a versatile platform designed for creating custom mobile applications and web interfaces for the remote control of microcontrollers and embedded systems using Wi-Fi, Bluetooth, and other communication protocols [42, 43].

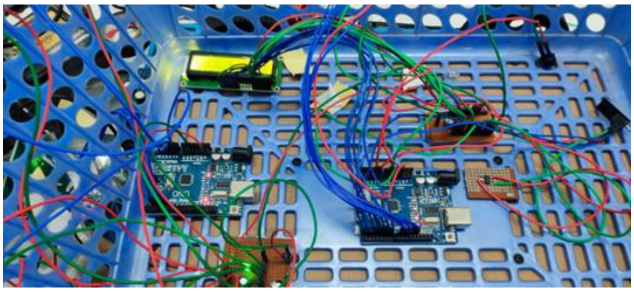
It enables users to control and monitor their projects remotely from smartphones, tablets, or computers. The platform offers a user-friendly drag-and-drop interface for designing custom user interfaces. It also includes a variety of pre-built widgets for controlling hardware components such as buttons, switches, sliders, and gauges. One of the distinctive features of Remote XY is its compatibility with a wide range of microcontrollers, including Arduino, Raspberry Pi, ESP32, ESP8266, among others. Users have the liberty to select the communication protocol that best fits their project requirements, such as Wi-Fi, Bluetooth, or USB. This adaptability has made Remote XY a preferred choice for both hobbyists and professionals who aim to remotely control and monitor their projects [42].

5 Results and Discussion

The prototype of the smart shopping basket, as depicted in Figures 6a and 6b, demonstrates the successful integration of RFID technology with the essential hardware components. The RFID system is adept at detecting and measuring the weight of items placed within the basket. The integrated LCD screen provides a real-time display of each item's cost, facilitating the shopper's ability to make informed decisions based on their running total.



(a) Top view of the shopping basket prototype



(b) Close-up view of the RFID and electronic components

Figure 6: Hardware connections of smart shopping basket prototype

This innovation addresses common consumer pain points, such as the time spent at checkout queues and the difficulty of tracking spending during shopping. Compared to traditional shopping methods, the smart basket offers an enhanced user interface that informs the shopper of their total expenditure in real time. This feature not only improves the shopping experience but also aids in budget management. However, the technology's reliance on the visibility and orientation of RFID tags could pose challenges in ensuring consistent performance. The current prototype's capability to measure item weight and display pricing information instantly sets it apart from conventional shopping methods. Future iterations of the smart basket could include more advanced features, such as integration with a store's inventory management system, personalized shopping recommendations based on consumer purchase history, and even the ability to sync with mobile payment systems for a seamless checkout process. The effectiveness of RFID in reducing checkout time has been validated through empirical testing, showing a high degree of accuracy and efficiency. Nonetheless, considerations must be made regarding the scalability of the system and the potential need for retailers to update their inventory practices to fully leverage the capabilities of RFID technology. In conclusion, the smart shopping basket prototype represents a promising direction in retail innovation. Continued development and integration with broader retail systems could redefine the shopping experience, offering benefits to both consumers and retailers alike.

6 Conclusion

Progress in science and technology is a continuous and dynamic process, with novel devices and technologies being constantly conceptualized and developed. This project has contributed to such advancements by leveraging RFID technology to enhance the shopping experience in retail centers. The employment of RFID technology served not only to ensure secure product access but also to bolster surveillance efficiency, addressing significant concerns in retail operations. The primary objective of this endeavor was to establish an automated billing system or central charging mechanism, aimed at eliminating the need for customers to queue at payment counters after their purchases. This innovation has resulted in a swifter billing process, streamlining and simplifying the overall transactional procedure.

Furthermore, the system's ability to detect theft attempts by fraudulent customers enhances its reliability and appeal to both customers and merchants, taking the shopping experience to a new level of efficiency and security. Looking ahead, it is recommended to explore the use of more powerful RFID readers with increased capacity to handle a greater number of products in the cart. Such advancements will likely further enhance the system's efficiency and reliability, thereby continuing the trend of innovation in retail technology and customer service.

Declaration of Competing Interests

The authors declare the following competing interests in relation to the development and discussion of smart cart technology utilizing Radio-Frequency Identification (RFID): Research Funding: The research and development of the smart cart using RFID technology discussed in this context have received partial funding from Thr Northcap university, which could affect the interpretation of the outcomes. Personal Interests: The authors acknowledge their personal belief in the transformative potential of RFID technology in enhancing smart cart functionality, which might influence my interpretations and opinions. Authors affirm that these competing interests do not compromise the objectivity or integrity of the information presented herein. Thus, the authors believe to have maintained transparency and offer this declaration to ensure transparency and allow readers to assess her perspectives with full awareness of potential biases.

Funding Declaration

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Author Contribution

Ipshita Datta: Conceptualization, Methodology, Data Curation, Software; **Anjali Garg**: Supervision, Writing - Review and Editing; **Anu Tonk**: Supervision, Writing - Review and Editing; **Pankaj Rakheja**; Supervision, Writing - Review and Editing

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