Implementation of radio frequency identification technology for a secure and intelligent shopping cart

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ABSTRACT

Shopping at supermarkets has become a daily activity in urban areas of Enugu, Nigeria. However, there is always a huge rush in most mega supermarkets during times of discount offers, weekends and holidays resulting in long queues due to the barcode billing process. This research proposes a way of reducing the time spent at the billing counter using a radio frequency identification (RFID) smart-based shopping cart. To achieve this objective, an RFID tag, RFID reader, Arduino microcontroller and light-emitting diode (LED) display were used to develop a smart shopping trolley. RFID tag was placed on each of the eight products displayed for sale. RFID reader reads all the products that were placed on the cart and the details of the product such as the name, quantity, cost, and total cost was displayed on the LED. The smart shopping trolley system also incorporates an alarm system that triggers off when the RFID tag is removed from a product to avoid shoplifting and make the system secure for the owners of the supermarket. The result showed that the billing of the products was done directly from the smart shopping cart. The system was compared with the conventional barcode system and was found to overcome the limitations of time-consuming billing procedures.

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1. INTRODUCTION

In today's fast-paced and digitally driven world, the retail industry is constantly evolving to improve operational efficiency and provide a seamless and convenient shopping experience for customers. Prominent retail stores such as Spar Supermarket, Four Market Days Supermarket, Roban Stores, and Shoprite in Enugu Metropolis, Nigeria provide shopping trolleys that play a crucial role in transporting customers' purchased items within the stores. However, these traditional shopping carts face challenges such as tracking the total cost of products, reducing long queues at checkout, preventing theft, and managing unauthorized item removal. These issues can lead to frustration and negatively impact the overall shopping experience. To address these limitations, the integration of radio frequency identification (RFID) technology into shopping trolleys offers a promising solution. RFID technology operates on the principle of wireless communication through radio waves. It automatically identifies, tracks, and captures information on objects equipped with

RFID tags, which contain unique identification codes and respond to an RFID reader without requiring direct line-of-sight or manual scanning [1]–[3].

Recent studies have highlighted the benefits of RFID technology in retail environments. Kasiri [4] outlined the advantages of RFID for inventory management and enhancing customer experience. Shrivastava [5] discussed how implementing RFID in smart shopping trolleys can improve efficiency and customer satisfaction. Additionally, Kommey *et al.* [6] explored RFID's role in theft prevention, showing how RFID-enabled trolleys can deter shoplifting and enhance security measures. Furthermore, innovative packaging technologies like intelligent packaging have been conceived to fulfill new market requirements for produce due to changes in retail and distribution practices associated with globalization, new consumer preferences, and emerging shopping channels [3]. Mamta and Sangwan [7] proposed using sensors on grocery shelves to automatically update the central server for inventory management, eliminating the need for manual scanning. Hanooja *et al.* [8] implemented a smart trolley with an automatic billing system that scans items placed on the trolley and displays the bill on a screen. However, this system had limitations in displaying the total bill and handling item removal. Patil *et al.* [9] improved this system by displaying the total bill on the screen, but cancellation of products still needed to be done at the billing point.

Despite these advancements, several gaps remain in the implementation of RFID technology in shopping trolleys. Existing systems often do not provide a real-time update of the total cost of items when an item is removed from the cart. Additionally, while some systems facilitate automatic billing, they still require customer intervention to remove items, and cancellation of products is typically done at the billing point, which does not entirely eliminate queuing. There is also a need for a more robust solution to prevent theft by ensuring that RFID tags cannot be easily removed without triggering an alarm.

This study seeks to enhance customer satisfaction by developing a smart shopping trolley that automatically tracks and displays the total cost of items, even if items are removed from the cart. This eliminates the need for line queuing during bill payment. Furthermore, the smart cart will trigger an alarm if an RFID tag is removed from any product, preventing shoplifting and enhancing store security.

The following sections of this paper will outline the methodology used to integrate RFID technology into shopping trolleys, describe the system architecture and components, and discuss the implementation process in detail. The results section will present findings from trials conducted in retail environments, demonstrating the effectiveness of the RFID-enabled smart trolleys in improving operational efficiency and customer satisfaction. Finally, the discussion will address potential challenges and future directions for further enhancing the technology. By addressing the current limitations and building on the contributions of previous studies, this research aims to provide a comprehensive solution that significantly improves the shopping experience and operational efficiency in retail stores.

2. THEORY OF WORK

2.1. Radio frequency identification technology

Radio frequency identification (RFID) technology is a wireless communication technology that enables automatic identification and tracking of objects using radio waves. RFID system consists of RFID tags, RFID readers and a backend system for data processing and analysis. RFID tags are small electronic devices that contain a unique identifier [10]. They can be active or passive and are usually attached to or embedded within objects. Active tags have their power source and can transmit data over longer distances while passive tags, on the other hand, do not have an internal power source and rely on the energy from the RFID reader to power them [11]. The RFID readers consist of an antenna, a transceiver, and a decoder. It emits radio waves through the antenna, captures the information stored in the tags and converts it into a readable format [12]. The backend system is a computer or a network of computers that processes, manages, and analyzes the collected data from the RFID reader. It may involve databases, software applications, and Algorithms to interpret and utilize the data effectively [13]. The basic RFID system is shown in Figure 1.

RFID technology has found applications in various industries due to its ability to improve efficiency, enabling real-time visibility and data capture. It enables accurate monitoring and tracking of inventory items, replacing manual inventory counting and improving operational efficiency. RFID technology plays a crucial role in supply chain management. It can track the movement of goods throughout the supply chain thereby improving the supply chain visibility and identifying the bottlenecks and inefficiencies [14]. RFID tags can be used as anti-theft measures to prevent shoplifting. RFID tags can trigger alarms if items are not paid for thus reducing theft incidents and improving overall security [15]. RFID technology enables retailers to gather customer data and preferences, offer targeted promotions and enhance customer engagement. RFID technology can be employed to optimize waste management processes by efficient monitoring and collection of waste, leading to improved waste disposal practices and reduced environmental impact [16]. RFID technology has found extensive applications in the healthcare industry, including patient tracking, asset management, medication administration, and inventory control.

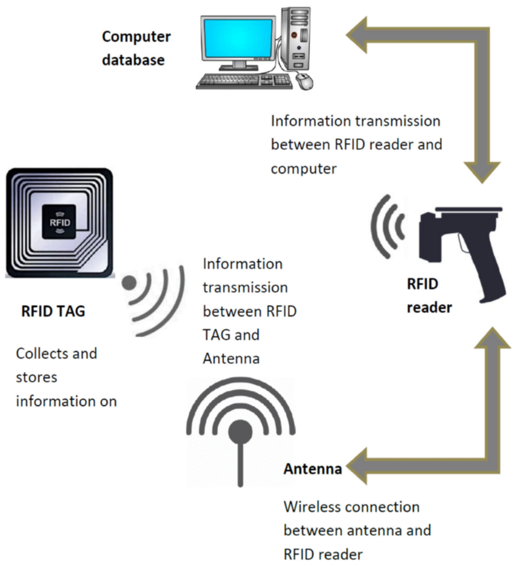

Figure 1. Basic radio frequency identification system

2.2. Arduino microcontroller

The Arduino microcontroller is an open-source electronics platform that consists of a programmable microcontroller board and a development environment. It provides an accessible and user-friendly platform for creating interactive electronic projects and prototypes [17]. Arduino boards are equipped with a microcontroller chip, which serves as the brain of the system. Arduino boards have a set of input/output (I/O) pins that can be used to connect and interact with sensors, actuators, and various electronic components [18]. These pins can be used as digital input or output pins, analog input pins, or specialized communication pins. Arduino boards can be expanded and customized using add-on modules that can be stacked on top of it to provide additional functionality such as wireless communication (Wi-Fi, Bluetooth), sensor integration, motor control and LCDs [19]. The Arduino board can be programmed using the Arduino integrated development environment (IDE) that allows users to write, compile, and upload code to it. The Arduino IDE is based on a simplified version of the C++ programming language and provides libraries and functions that make it easier to interact with the microcontroller's hardware. The most used microcontroller in Arduino boards is from the Atmel AVR family, such as the ATmega328P, ATMega4809, and ATMega2560 [20]. However, other microcontrollers like ARM-based chips are also compatible with Arduino. The Arduino microcontroller is shown in Figure 2. Arduino is not a single microcontroller model, but a platform that encompasses various boards with different features and capabilities. The specific board chosen depends on the project requirements.

2.3. Barcode system

A barcode system is a technology that uses barcode symbols to encode and store information in a visual format. It involves the use of barcode scanners or readers to capture and decode the information contained within the barcode [21]. Barcodes are graphical representations of data in the form of a series of parallel lines or squares, along with accompanying numbers or alphanumeric characters. The most common type of barcode is the one-dimensional (1D) barcode, which consists of vertical lines of varying thickness. However, there are also two-dimensional (2D) barcodes that can store more data in a smaller space using patterns of dots, squares, or other shapes [22], [23]. Barcode labels or tags are physical representations of barcodes that are affixed to products, packaging, or assets. These labels contain the barcode pattern along with any additional human-readable information, such as product names or prices. Barcode labels can be printed on adhesive labels, tags, or directly marked on items using technologies like direct part marking (DPM). Barcode scanners or readers are devices that use light sensors or lasers to capture and interpret the information encoded in barcodes [24]. The scanner emits light, typically a laser beam or LED, which reflects off the barcode. The reflected light is then detected by a photosensitive element in the scanner, which converts it into electrical signals. The scanner decodes these signals to retrieve the encoded information. Barcode scanners or readers can be handheld, fixed-mounted, or integrated into mobile devices. The backend system of a barcode system involves software applications and databases that manage and process the barcode data. This system can be a computer server or a cloud-based platform. It receives the scanned barcode data, performs actions such as inventory updates, product lookup, or data storage, and generates reports or analytics based on the collected information [25]. The barcode system is shown in Figure 3 and is widely used in various industries for product tracking, inventory management and retail operations.

Figure 2. Arduino microcontroller

Figure 3. Barcode system

2.4. Radio frequency identification versus barcode systems

RFID systems and barcode systems are both used for identification and data capture, but they have distinct differences in terms of technology, functionality, and application. RFID technology offers several advantages over traditional barcode systems. Table 1 shows the comparison between RFID and barcode systems.

Table 1. Comparison between RFID and barcode systems

Features	RFID system	Barcode system
Technology	RFID uses radio frequency signals to wirelessly transmit data between an RFID reader and an RFID tag. RFID systems can operate in different frequency ranges, including low frequency (LF), high frequency (HF), and ultra-high frequency (UHF).	Barcodes use visual patterns of bars and spaces to represent encoded information. They are scanned using barcode readers that use light sensors or lasers to capture the barcode data. Barcodes rely on the line-of-sight scanning method.
Read range and speed	RFID systems can read multiple tags simultaneously and at a much greater distance without direct visibility allowing for faster and more efficient data capture.	Barcodes require proximity and line-of-sight scanning, limiting the read range to a few centimeters. Barcode scanners need to scan each barcode individually, which can be time-consuming in large-scale operations.
Data capacity	RFID tags have larger data storage capacity. They can store unique identifiers, product details, manufacturing information, and other data.	Barcodes have limited data capacity and usually contain product-specific information such as item number or stock-keeping unit (SKU).
Durability and longevity	RFID tags are typically more durable and resistant to wear and tear. They can withstand harsh environmental conditions.	Barcodes are typically less durable and resistant to wear and tear.
Real-time tracking	RFID technology allows for real-time tracking of items as they move through the supply chain. This automation improves efficiency.	Barcode systems, which require manual scanning at each checkpoint. Automation is limited.
Security	RFID tags can be equipped with security features such as encryption and authentication, making them more secure than barcodes.	Barcode systems are not secure.
Cost	RFID systems typically have a higher upfront cost due to the complexity of the technology and the need for specialized equipment. However, the long-term benefits and potential cost savings in improved efficiency can outweigh the initial investment.	Barcode systems are relatively more affordable and accessible, as barcode labels and scanners are widely available and cost-effective.

3. METHOD

Adhesive RFID tags were attached to six products to uniquely identify them. Each RFID tag was programmed with a unique identifier and relevant product information such as the name and price. The MFRC522 RFID reader module was employed, interfacing with an Arduino Uno microcontroller. An Arduino Uno board was utilized to manage RFID communication and process data. The MFRC522 RFID reader module was connected to the Arduino Uno using specific pins for power (3.3 V), ground (GND), and communication (SDA, SCK, MOSI, and MISO). Proper pin connections were ensured for reliable data transmission. The MFRC522 library was installed in Arduino IDE to facilitate RFID communication. The MFRC522 RFID reader was configured to read data from the scanned RFID tags, calculate the total cost of the items in real-time, display the total cost on the integrated screen of the shopping trolley for the customer to view and communicate with the central software system using the pseudocode in Algorithm 1. The MFRC522 RFID reader was strategically positioned on the shopping trolley to ensure effective scanning of the RFID tags. A queueing management system was also incorporated in the pseudocode of the smart trolley system shown in Algorithm 1. This was done to assign customers to available checkout counters to eliminate line queuing. Also, the system was configured to compare the items in the shopping trolley with the scanned RFID tags during the checkout process to prevent shoplifting. Algorithm 1 presents a pseudocode indicating the steps adopted in the hardware and software implementation of the smart trolley shopping system, while Figure 4 shows the flowchart of the smart cart system.

Algorithm 1. Pseudocode for the hardware and software implementation of the smart trolley shopping system

```
Pseudocode
Step 1: Hardware Setup
    •   Connect the MFRC522 RFID reader module to the Arduino board according to the
        pinout instructions provided by the manufacturer. Ensure that the RFID reader
        module is receiving power from the Arduino and the necessary communication pins
        (e.g., SDA, SCK, MOSI, MISO) are correctly connected. These connections are
        illustrated in Figure 5 (Schematic Circuit of the Smart Cart System)
Step 2: Install Libraries
    •   In the Arduino IDE, go to "Sketch" -> "Include Library" -> "Manage Libraries".
             Install the "MFRC522" library by "GithubCommunity" for RFID communication.
Step 3: Program Setup
    •   Open a new Arduino sketch in the Arduino IDE.
Step 4: Import Libraries and Define Variables using the code below
#include <SPI.h>
#include <MFRC522.h>
#define SS_PIN 10
#define RST_PIN 9
MFRC522 mfrc522(SS_PIN, RST_PIN);//Create MFRC522 instance
//Define product information and prices
struct Product {
  String name;
  int price;
};
Product products[]={
  {"Jacobs Cream Crackers", 730},
  {"Checkers Custard Satchet", 80},
  {"Shortcake bread", 90},
  {"Peak Milk", 770},
  {"Nestle Milo", 720},
  {"Great Hall Staples", 120},
  {"Klin Bar Soap", 80},
  {"Kellogs Cornflakes", 1810}
};
const int numProducts=sizeof(products) / sizeof(products[0]);

Step 5: Setup Function
    •   Set up the RFID reader in the setup() function:
void setup() {
  Serial.begin(9600);
  SPI.begin();
  mfrc522.PCD_Init();
  // Additional setup code for communication with the central software system
}

Step 6: Loop Function
    •   Continuosly Read RFID tag data, calculate total cost, display on the shopping
        trolley, and handle checkout counter availability in the loop() function:
void loop() {
  // Check if a new RFID tag is detected
  if (mfrc522.PICC_IsNewCardPresent() && mfrc522.PICC_ReadCardSerial()) {
```

```
    // Read the RFID tag UID
    String rfidTag = "";
    for (byte i = 0; i < mfrc522.uid.size; i++) {
      rfidTag += String(mfrc522.uid.uidByte[i], HEX);
    }
    // Search for the product associated with the RFID tag
    int productIndex = -1;
    for (int i = 0; i < numProducts; i++) {
      if (rfidTag == products[i].name) {
        productIndex = i;
        break;
      }
    }
    // Calculate total cost and display on the trolley screen
    int totalCost = 0;
    if (productIndex != -1) {
      totalCost = products[productIndex].price;
    }
    displayTotalCost(totalCost);

    // Check for available checkout counters
    boolean checkoutAvailable = isCheckoutAvailable();
    // Perform actions based on checkout counter availability
    if (checkoutAvailable) {
      displayTotalCostOnCheckout(totalCost);
    } else {
      triggerAlarm();
    }
    mfrc522.PICC_HaltA();
  }
}
void displayTotalCost(int cost) {
  // Code to display the total cost on the cart's integrated screen
  Serial.print("Total Cost: $");
  Serial.println(cost);
}
boolean isCheckoutAvailable() {
  // Code to check for available checkout counters
  return true; // Replace with actual implementation
}
void displayTotalCostOnCheckout(int cost) {
  // Code to display the total coston the checkout counter's screen
  Serial.print("Total Cost on Checkout Counter: $");
  Serial.println(cost);
}
void triggerAlarm() {
  // Code to trigger the alarm system
  Serial.println("ALARM: Shoplifting detected!");
}

Step 7: Upload the Sketch
Verify and upload the sketch to the Arduino board
```

The pseudocode in Algorithm 1 was employed in configureing the RFID reader to communicate with the central software system. The program scans an RFID tag and checks if the scanned RFID tag is valid by comparing it with the unique identifiers of the six RFID tags. If the RFID tag is valid, the program retrieves the relevant product information (such as product name and price). The program displays the product information on the integrated screen of the shopping trolley for the customer to view and add the product to the shopping trolley. It then detects the availability of checkout counters for a seamless checkout experience. If a checkout counter is available, the program displays the total cost on the screen of the available checkout counter and triggers the alarm system if any items detected in the cart are not associated with scanned RFID tags. The integration of RFID technology, real-time cost calculation, and queue management addresses common retail challenges, offering a streamlined and secure shopping experience.

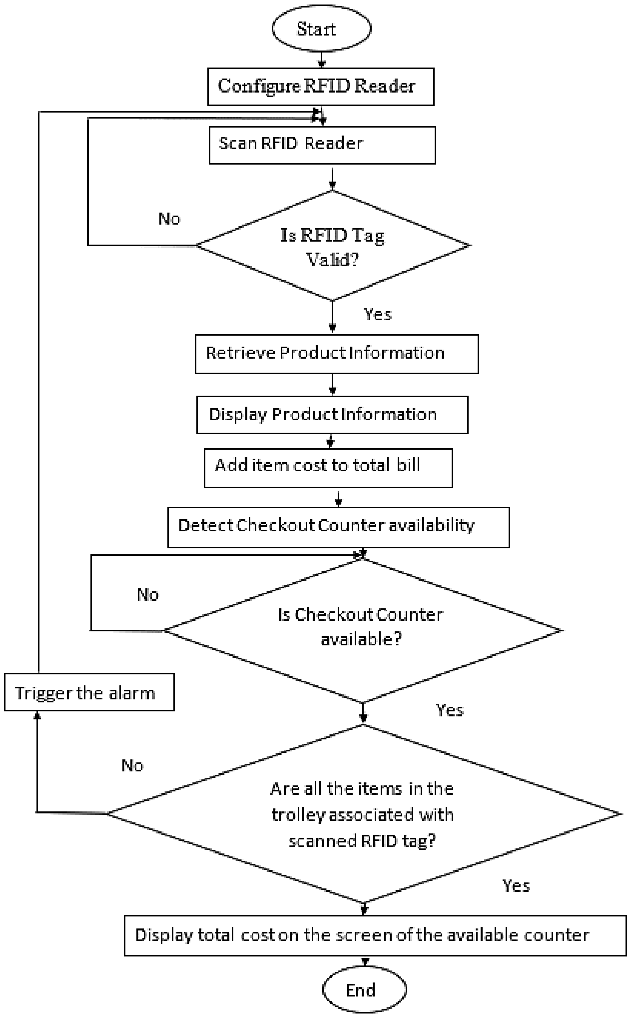

Figure 4. Flowchart of the smart cart system

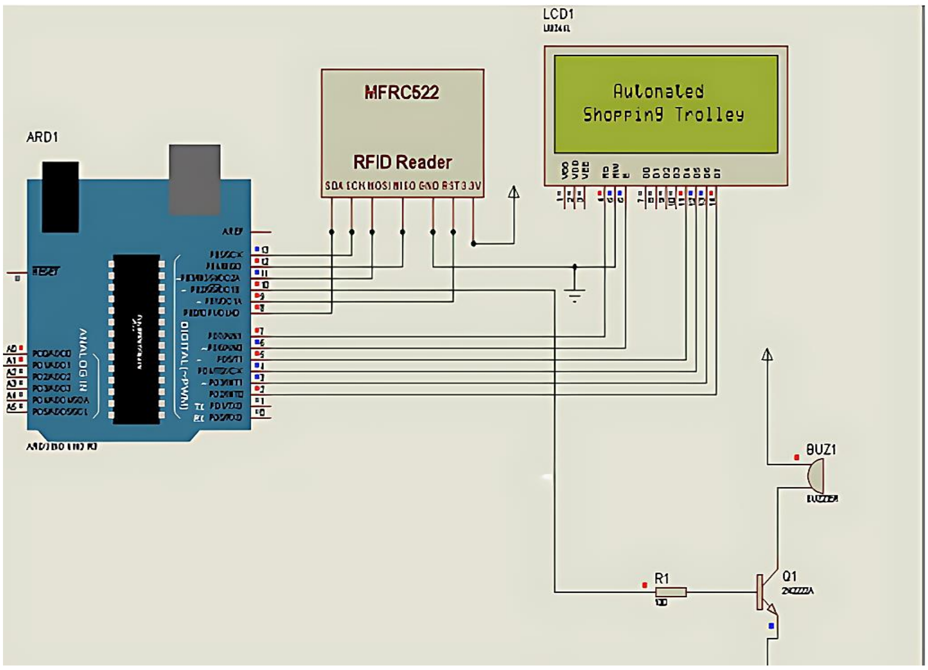

Figure 5. Schematic circuit of the smart cart system

4. RESULTS

The developed smart-based shopping cart is shown in Figure 6. The image shows that the cost of an item placed in the smart trolley system is displayed on the LCD screen in Figure 6(a); as well as the total cost of the eight items as shown in Figure 6(b). This will help the customer to see the total cost of items and manage their budget effectively. This feature is particularly useful for customers who want to keep track of their spending in real-time. The smart shopping cart system was tested with 30 participants to evaluate its performance against a conventional barcode-based system. The key findings are summarized in Table 2.

(a) (b)

Figure 6. Smart trolley system; (a) with an item and (b) with eight items

Table 2. Performance comparison of smart trolley and barcode systems

Metric	Smart trolley system	Barcode system
Average time for checkout (min)	4	20
Total items processed	240	240
Average time per item (sec)	1	5
User satisfaction score (1-10)	9	2

The smart shopping cart significantly reduced the time required for checkout. It took an average of 4 minutes for the cashier to receive payment and package the items using the smart trolley system, compared to 20 minutes with the barcode system. This reduction in time is due to the automated scanning of RFID tags, which eliminates the need for manual barcode scanning. Participants reported higher satisfaction with the smart trolley system, giving it an average score of 9 out of 10, compared to 2 for the barcode system. The ease of use and time-saving aspects were highlighted as the main reasons for this preference. The results indicate that the smart trolley system is more efficient and user-friendly compared to traditional barcode systems. The reduced checkout time and improved user satisfaction suggest that this technology could revolutionize the retail industry by providing a faster and more enjoyable shopping experience. Faster checkouts can lead to increased customer throughput, reduced queue lengths, and improved customer satisfaction. Additionally, the system’s ability to detect and prevent shoplifting by comparing items in the trolley with scanned RFID tags enhances security. Previous studies have shown that RFID technology can streamline retail operations, but few have quantified the time savings as clearly as this study. The significant reduction in checkout time aligns with findings from studies that emphasize the efficiency of RFID over barcode system.

5. CONCLUSION

The smart-based shopping cart system represents a transformative advancement in the retail industry, addressing long-standing challenges and setting a new standard for modern shopping experiences. In this work, the shopping cart keeps a count of items, displays the total cost of purchased items and triggers the alarm system to prevent shoplifting thereby making it smart and secure. By reducing checkout times, enhancing customer satisfaction, and bolstering security measures, this system offers significant benefits to both retailers and customers. The findings from this study indicate that widespread adoption of this technology could lead to substantial improvements in retail operations and customer experiences.

Furthermore, as technology continues to advance, the potential for further enhancements in smart shopping trolley systems is vast. Future developments could include the integration of inventory management, providing real-time inventory updates as items are scanned into the trolley, reducing out-of-stock situations and customer loyalty programs. The implications of these advancements are profound, suggesting a future where shopping is not only more efficient and secure but also more engaging and tailored to individual preferences. As the retail industry embraces these technological innovations, it stands to benefit from increased operational efficiency, reduced costs, and higher levels of customer satisfaction and loyalty. Ultimately, the continued evolution of smart shopping cart systems holds the promise of revolutionizing the way we shop, creating a more seamless, enjoyable, and efficient retail experience for all.

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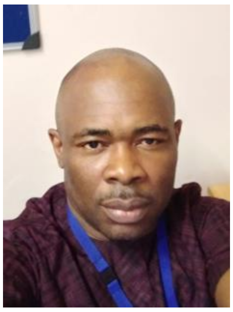

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