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Smart Trolley

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Abstract: ***This paper presents an integrated smart trolley system developed to improve efficiency in modern retail environments. The system combines two key functions: an Autonomous Human-Following (AHF) module that allows the trolley to move hands-free by following the user, and an RFID-based Automated Billing (RAB) module that enables real-time product identification and billing. A dual-microcontroller architecture is used to independently manage mobility control and billing operations, ensuring reliable and smooth performance. The human-following feature uses ultrasonic sensors to maintain a safe distance from the customer, while the billing module automatically updates item details and total cost as products are added or removed. By reducing manual effort and checkout delays, the proposed system enhances shopping convenience and user experience. The effectiveness of the design is demonstrated through experiments conducted on a working laboratory prototype, with results showing improved responsiveness and reliable operation compared to conventional shopping methods.***

I. INTRODUCTION

Automation has been widely adopted in modern electronics across industrial, commercial, and consumer sectors. In the retail industry, the move from manual processes to automated systems has become essential for improving customer convenience and operational efficiency. Rapid population growth and increasing urbanization have resulted in heavy customer traffic in supermarkets and hypermarkets. Despite this, the basic shopping tool—the manual trolley—has seen very little improvement over the years, leading to both physical discomfort and time-related inefficiencies.

Traditional shopping presents two major challenges. First, customers must exert considerable physical effort to push heavily loaded trolleys through crowded aisles. Second, long waiting times at billing counters, often referred to as the "queueing effect," significantly reduce shopping efficiency. Conventional barcode-based billing systems require each item to be scanned individually with a clear line of sight, making the process slow and prone to human error. As the number of purchased items increases, the effort needed to move the trolley also rises, which can be especially difficult for elderly customers and individuals with physical limitations. To address these issues, this project proposes an integrated smart trolley system that combines automated mobility and intelligent billing into a single platform. The system uses a decentralized multi-controller architecture to perform multiple tasks simultaneously. One controller function as a navigation engine, enabling the trolley to autonomously follow the customer using ultrasonic time-of-flight calculations. The second controller serves as a transaction engine, employing Radio Frequency Identification (RFID) technology to provide seamless, real-time billing. By integrating mobility and commerce rather than treating them as separate functions, the proposed system offers a hands-free shopping experience and an instant "checkout-as-you-go" process, resulting in higher efficiency and improved customer satisfaction compared to traditional manual trolleys.

II. SYSTEM CONFIGURATION

The proposed smart trolley is designed with a modular system architecture to improve performance and response time. Instead of handling all tasks in a single unit, the system is divided into two specialized modules. This approach allows the trolley to process movement control and data handling simultaneously, resulting in smoother operation and faster decision-making.

A. Autonomous Human-Following and Navigation Unit

The mobility of the smart trolley is controlled using an ultrasonic time-of-flight (ToF) sensing system. An array of ultrasonic sensors continuously emits high-frequency sound waves to detect the position of the customer. The distance is calculated by measuring the time taken for the emitted pulse to return after hitting an object, enabling real-time and accurate distance estimation.

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To ensure safe and comfortable movement, this unit operates based on a predefined "Safe Zone" tracking mechanism. The trolley automatically adjusts its speed by varying the pulse-width modulation (PWM) signals supplied to the motor driver, matching the customer's walking pace. This prevents sudden collisions as well as excessive gaps between the trolley and the user. By dedicating a separate microcontroller to navigation and human-following tasks, the system achieves reliable tracking and stable performance, even in crowded or dynamic environments where obstacles and human movement continuously change.

B. RFID-Based Transaction and Processing Unit

The smart trolley uses a separate dedicated microcontroller to manage billing and product transactions efficiently. This unit acts as the Transaction Engine, responsible for handling all commercial data and inventory-related operations. Product identification is achieved using RFID technology operating at 13.56 MHz, ensuring fast and contactless scanning.

1) Intelligent Data Logging: When a product carrying a unique RFID tag is placed inside the trolley, the reader instantly detects its UID. The system then matches this UID with an internal, structured database to retrieve the corresponding product name and price. This process happens automatically, enabling quick and error-free item logging.

2) Touch-Sensitive User Interface: To enhance user comfort and provide a modern interface, the system uses TTP223 capacitive touch sensors instead of conventional mechanical push buttons.

These touch inputs control essential billing operations:

a) Add Mode: The default operating mode, used to add the price of a scanned product to the total bill.

b) Remove Mode: Activated through a touch input, allowing users to subtract an item if they choose not to purchase it, maintaining billing accuracy and transparency.

c) Reset Mode: Clears all transaction data and resets the total bill once the purchase is completed.

3) Visual Feedback: All transaction details, including item information and the running total, are displayed on a 16×2 LCD connected via the I²C protocol. This provides real-time visual feedback, enabling customers to track their expenses easily without manual calculations. By separating the Navigation Hub from the Billing Hub, the system prevents electrical noise and processing delays caused by motor control from affecting sensitive billing operations. This modular design ensures reliable movement control and secure, accurate transaction processing

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III. PERFORMANCE ANALYSIS OF THE SYSTEM

The performance of the Smart Trolley is evaluated based on the responsiveness and reliability of its dual-processor architecture. By separating motion control and billing operations, the system efficiently transforms raw sensor inputs into smooth mechanical actions and clear audio-visual feedback, significantly reducing user effort during operation.

A. Performance of the Autonomous Human-Following (AHF) Module

The navigation module employs a triple ultrasonic sensor arrangement to continuously track the user's position. Based on the measured distance, the control algorithm dynamically regulates motor behavior by dividing operation into three distinct zones:

- Safety Zone (Distance > 75 cm):
  When the user moves beyond the tracking range, the motors are released, and the system enters standby mode. This prevents unnecessary movement and ensures the trolley remains stationary when the user is not nearby.
- Follow Zone (27 cm – 75 cm):
  Within this optimal tracking range, the trolley performs smooth forward motion at a controlled PWM speed of 122. If lateral displacement is detected, differential steering is applied by varying motor speed by ±70 PWM units, allowing accurate pivoting and continuous alignment with the user.
- Danger Zone (Distance < 27 cm):
  If the user comes too close, an immediate electronic braking action is applied to all motors. This rapid response maintains a safe buffer and prevents collisions during sudden stops or direction changes.

Overall, the AHF module demonstrates stable tracking, fast response, and safe operation in dynamic environments.

B. Performance of the RFID-Based Automated Billing (RAB) Module

The billing module is optimized for fast and transparent transaction processing. Using an efficient polling mechanism, the system converts RFID tag data into instant user feedback and accurate billing updates.

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- Scan Confirmation:
  Each successful RFID scan generates a short, high-frequency beep, confirming that the product has been correctly identified and recorded.
- Mode Selection Using TTP223 Touch Switch:
  Add Mode: By default, the system retrieves the product price from the internal database and updates the I²C-connected LCD within milliseconds. Remove Mode: Activated via a TTP223 touch input, enabling users to subtract the price of a returned or unwanted item from the total bill. System Reset: A dedicated TTP223 reset touch sensor clears all transaction data and resets the bill amount to zero. This allows the trolley to be reused immediately without a power cycle, improving efficiency in high-traffic environments.

The Smart Trolley operates using a synchronized dual-controller architecture, where two independent microcontrollers handle motion control and transaction processing. This coordinated design ensures fast response to user movement and accurate product billing, delivering a smooth and efficient shopping experience.

1) Operation of the Human-Following Unit

The Autonomous Human-Following (AHF) unit functions by continuously analyzing distance information obtained from a triple ultrasonic sensor array using the Time-of-Flight (ToF) principle.

- Sensing Phase:
  The controller sequentially triggers the left, center, and right ultrasonic sensors. The distance to the user is calculated by measuring the time taken for the emitted ultrasonic pulse to return as an echo. To improve accuracy and minimize noise, the system averages three consecutive readings from each sensor using a filtered distance function.
- Decision Phase:
  The filtered distance values are compared with predefined safety thresholds. If an object is detected within the maximum tracking range of 75 cm and beyond the minimum stop distance of 27 cm, the controller determines the direction of movement:

When the center sensor is active, the forward function drives all four DC motors for straight movement.
When the left or right sensor detects the user, the system performs differential steering by adjusting the PWM duty cycles of the inner and outer motors, allowing the trolley to pivot smoothly toward the user.

- Actuation Phase:
  The calculated control signals are sent to the L298N motor driver, which amplifies the low-power logic signals into high-current outputs. This enables stable motion of the four-wheel chassis while maintaining a safe and consistent following distance.

2) Operation of the Automated Billing Unit

The RFID-Based Automated Billing (RAB) unit acts as a real-time transaction engine, using electromagnetic coupling at 13.56 MHz to identify products and manage billing operations.

- Identification Phase:
  The MFRC522 RFID reader generates an electromagnetic induction field. When a passive RFID tag attached to a product enters this field, its unique identification number (UID) is transmitted to the controller.
- Processing Phase:
  The received UID is matched against a structured internal database containing product names and prices. Based on the active operating mode, the system either adds the item price to the total bill or subtracts it if the item is removed.
- User Interface and Mode Control:
  To improve durability and ease of use, the system employs TTP223 capacitive touch sensors instead of mechanical switches:
  Add Mode: Default mode, where scanning an item increases the total amount.
  Remove Mode: Activated via a touch input, allowing the user to return an item and update the bill accordingly.
  Reset Mode: Clears all session data and resets the total amount to zero, preparing the trolley for the next customer.
- Feedback Phase:
  Every successful operation triggers a short audio beep through a buzzer and updates the I²C-connected 16×2 LCD with the product name and current total, providing immediate and clear feedback to the user.

3) Operational Logic Flow Summary

By separating high-current motor control and sensitive data processing across two microcontrollers, the system achieves high operational efficiency and reliability. This isolation minimizes electromagnetic interference (EMI) from motor transients, preventing disruption of RFID communication and ensuring accurate navigation and billing performance.

a) Technical Specification

Component	Specification
Microcontroller	Aurduino UNO(ATmega328P)
Operating Voltage	5V DC
Input Power Source	7-12 V DC Battery
Sensing Technology	Ultrasonic Distance Sensing (HC-SR04)
Number of Sensors	3 (Left, Center, Right)
Communication Interfaces	SPI (RFID), I2C (LCD) Digital I/O
RFID Technology	13.56 MHz RFID (RC!
Display Unit	16 x 2 LCD with I2C module
Motor Driver	L293D Motor Driver Shield
Drive Motors	4 x DC Geared Motor
User Input	Capacitive Touch Sensors
Alert System	Active Buzzer
Programming Platform	Arduino IDE (Embedded C)
System Type	Embedded Real-Time System

The HC-SR04 ultrasonic sensor is employed for non-contact distance measurement in the human-following navigation subsystem. The sensor operates by transmitting ultrasonic pulses and calculating distance based on the time-of-flight of the reflected echo signal. Three ultrasonic sensors are mounted at the left, center, and right positions of the trolley to enable directional detection and real-time navigation control. The Arduino UNO, based on the ATmega328P microcontroller, serves as the primary processing and control unit. It performs sensor data acquisition, decision-making logic, motor control, RFID data processing, and display management. The RC522 RFID module is utilized for contactless identification of products in the automated billing subsystem. Each product is associated with a passive RFID tag containing a unique identifier.A 16 × 2 alphanumeric LCD module is interfaced with the microcontroller through the I2C protocol to provide real-time system information and billing details.

The L293D motor driver shield is used to interface the microcontroller with DC motors. It provides bidirectional control and sufficient current amplification while isolating the control circuitry from motor load currents. DC geared motors are employed to achieve controlled motion of the trolley. The use of multiple motors ensures balanced movement and improved load handling capability. Capacitive touch sensors are used as digital input devices for user interaction with the billing system, enabling mode selection operations. A 1kΩ resistor is connected in series at the output of the touch switch to limit current, protect the microcontroller I/O pin, and improve signal stability during operation.

An active buzzer is incorporated to provide audible feedback corresponding to system events and user actions. The system uses a dual-voltage power supply to meet the requirements of control and drive components.

IV. DESIGN OF THE SYSTEM

The block diagram of the proposed Smart Shopping Trolley system is shown in the above figure. The system is composed of several functional blocks, including the power supply unit, human-following unit, RFID-based billing unit, user interface unit, control unit, and the display and alert unit. Together, these blocks work to automate both trolley movement and the billing process, making shopping more convenient and efficient.

The system is divided into two main functional units: the human-following unit and the automated billing unit. The human-following unit includes ultrasonic sensors, a motor driver circuit, and DC motors. The ultrasonic sensors continuously measure the distance between the trolley and the user. Based on this distance information, appropriate control signals are generated to adjust the speed and direction of the motors, allowing the trolley to smoothly follow the user while maintaining a safe distance.

The automated billing unit consists of an RFID reader, capacitive touch sensors, an LCD display, and a buzzer. The RFID reader identifies products by scanning their RFID tags, while the touch sensors allow the user to select add, remove, or reset operations. The system processes the scanned product data and updates the total bill amount in real time, which is displayed on the LCD. The buzzer provides audible feedback to confirm user actions and system events.

The control unit plays a central role in the system by coordinating all operations. It handles sensor data acquisition, executes control logic, processes RFID information, and generates the necessary control signals for motor control and user interaction. The display and alert unit provide real-time visual and audio feedback, informing the user about system status and billing details.

Overall, the proposed Smart Shopping Trolley system combines autonomous navigation with automated billing through coordinated sensing, processing, and actuation, resulting in a practical, user-friendly solution for modern shopping environments.

V. CONCLUSION

The Smart Shopping Trolley system successfully combines human-following navigation with an automated billing process to improve convenience and efficiency during shopping. By using ultrasonic sensors for tracking the customer and RFID technology for identifying products, the system enables the trolley to move automatically while calculating the bill in real time. This approach reduces physical effort for users and helps eliminate long checkout queues.The system is developed using affordable and easily available components such as the Arduino UNO, HC-SR04 ultrasonic sensors, RC522 RFID module, and DC motors. Testing results show that the trolley follows the user smoothly, maintains safe distances, and performs billing operations accurately. The LCD display, touch-based controls, and buzzer provide clear feedback, making the system easy to understand and operate.In the future, the system can be further enhanced by integrating an ESP32 microcontroller to support IoT-based cloud billing and real-time data synchronization. Adding a load cell for weight measurement can help verify scanned items and improve billing accuracy and security. With these improvements, the Smart Shopping Trolley has strong potential to be adapted for smart retail environments and real-world commercial applications.

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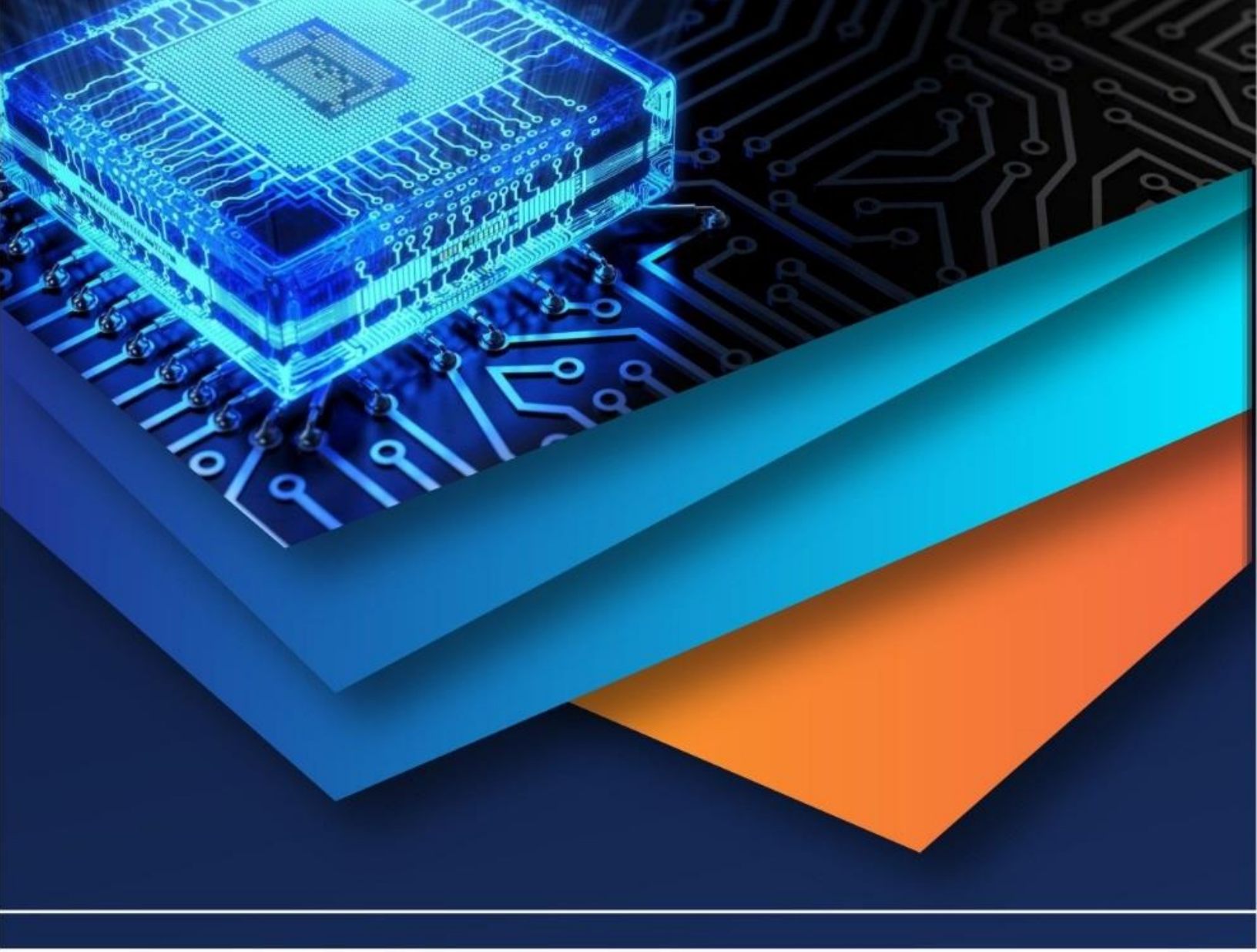

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