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IoT- Based Intelligent Navigation Shopping Trolley with Voice Interaction and RFID Product Recognition for Visually Impaired Shoppers

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Abstract: This paper presents an IoT based intelligent shopping trolley designed to assist visually impaired users through voice guided navigation [6],RFID based product section detection [3] and real time obstacle monitoring [18]. The system integrates Raspberry Pi and Arduino to support hands free interaction using speech input ultrasonic sensing and RFID based confirmation. Experimental evaluation shows that the prototype performs reliably in indoor shopping conditions. The system achieved a Voice Command Recognition Accuracy of 93 % [6] an Obstacle Detection Reliability of 93 percent [18] a Section Identification Success Rate of 100 percent [3] and an average Response Latency of 1.2 seconds [21]. These results indicate that the proposed solution can guide users accurately identify sections and provide timely alerts during movement. Overall the findings suggest that the system offers a practical approach to supporting independent shopping for visually impaired individuals.

Keywords: IoT, RFID, Ultrasonic Sensor, Voice Interaction, Navigation, Assistive Technology.

I. Introduction

Shopping inside a supermarket is difficult for individuals with visual impairment because product identification aisle navigation and section recognition typically depend on visual information. Without external help many users struggle to locate products safely move through aisles or understand shelf arrangements which limits their independence [17]. Existing solutions such as RFID based carts and voice enabled assistance systems help identify products but provide limited navigation support and rely on the user to independently move through the store [2] ,[3] ,[5]. The absence of real time mobility guidance remains a major barrier since obstacles can appear unexpectedly and aisle layouts vary across stores.

To address this limitation the present work introduces an IoT based shopping trolley that provides spoken instructions RFID assisted section detection and continuous obstacle awareness. The trolley interprets user voice commands [6] determines the destination section using stored RFID mappings [3] and guides the user step by step using onboard audio output. Ultrasonic sensing improves safety by alerting the user to nearby objects during movement [18]. This integrated approach focuses on mobility support rather than only product scanning or billing.

The main contribution of this paper is the implementation and experimental evaluation of a functional prototype that combines these features into a single assistive platform. The performance of voice recognition obstacle detection section identification and system response time is measured to demonstrate practical feasibility in an indoor environment [1] [5] [18].

II. Existing System

Earlier research studies have introduced multiple smart shopping solutions aimed at supporting visually impaired individuals through automation, sensing and guided feedback. Many of these systems primarily rely on RFID tags to identify products and assist users in recognizing items placed on supermarket shelves [2], [3]. RFID based carts reduce the burden of manual scanning by automatically detecting tagged goods, but they still require the user to navigate the store independently.

Other approaches incorporate voice announcements or mobile applications to convey product information, enabling users to understand details without visual inspection [5]. Although helpful, these methods do not address mobility challenges because they lack obstacle detection and real time navigation support. Further advancements include electronic trolleys that use prepaid cards, smart billing modules and barcode recognition systems to simplify checkout processes [7], [8]. These solutions mainly focus on the purchase and payment aspects rather than full movement assistance.

Several systems have also explored embedded sensors such as ultrasonic modules to alert users about nearby obstacles during navigation [18], as well as IoT based communication between store infrastructure and smart carts to deliver location hints [7]. However, such systems often provide isolated functions and do not integrate speech input, obstacle sensing and section identification into a unified platform.

Although these existing solutions offer partial support, they do not deliver combined navigation guidance, section level identification and obstacle aware movement. These limitations highlight the need for an integrated assistive system, which motivates the implementation presented in this paper.

III. Proposed System

The proposed system introduces an intelligent shopping trolley that assists visually impaired users by combining voice interaction, RFID based section detection and obstacle aware navigation. The architecture integrates a Raspberry Pi as the main processing unit and an Arduino Uno to manage sensors and RFID communication, a structure commonly used in lightweight IoT assistive systems [21], [22].

At the start of a shopping session, the trolley is activated through an RFID entry tag. RFID based identification has been widely applied in earlier assistive shopping solutions to simplify section detection and product recognition [2], [3]. Once the system is activated, the Raspberry Pi prompts the user to speak the desired product section. The microphone captures the user's speech, and the Pi processes the command using a speech recognition engine, following principles demonstrated in recent voice assisted navigation technologies for visually impaired users [6].

After interpreting the command, the system maps the request to a predefined section ID linked to RFID tags placed at store shelves. The Pi then generates stepwise movement instructions and delivers them through the onboard speaker, enabling the user to follow the correct route without visual cues. Throughout this movement, the Arduino continuously monitors the ultrasonic sensor. Ultrasonic ranging has shown high reliability for alerting users about nearby obstacles in indoor assistive systems [18], making it suitable for safe navigation within supermarket aisles.

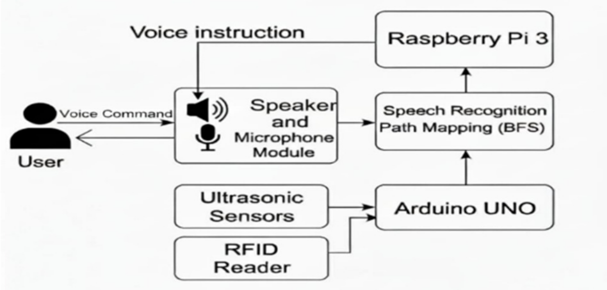

Fig. 1. System architecture.

Fig 1: System Architecture

When the trolley reaches the correct area, the RFID reader detects the shelf tag, confirms the section and announces the arrival message through voice output. The user can then request another section or choose to navigate toward the exit. This cycle continues until the user completes the shopping session.

By combining voice control [6], RFID based location confirmation [3] and ultrasonic sensing for obstacle awareness [18], the proposed system provides an integrated mobility solution that supports independent indoor navigation for visually impaired shoppers. The design shifts from simple billing automation seen in previous trolleys to a more comprehensive and safety oriented navigation approach [1], [5].

IV. Methodology

The methodology outlines how the intelligent trolley interprets user commands, plans movement and verifies section locations through coordinated interaction between the Raspberry Pi and Arduino. The workflow is divided into four major stages: system activation, command interpretation, route execution and section confirmation.

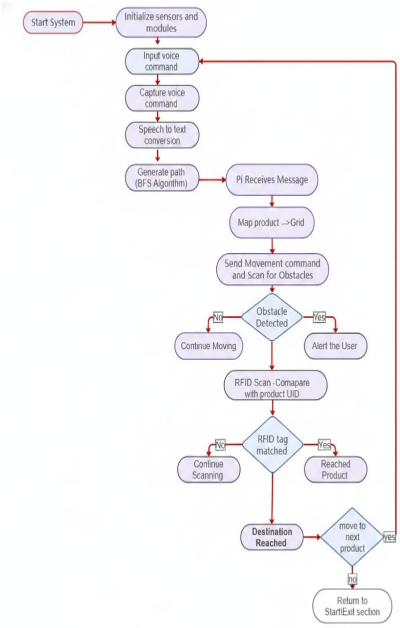

Fig. 2. Flow diagram of navigation, obstacle detection and RFID-based section confirmation.

1. System Activation

The process begins when the user scans the entry RFID tag placed at the store entrance. Once detected, the Arduino sends the tag information to the Raspberry Pi, which initializes the navigation program and prepares the system to receive audio commands. RFID based triggers have been widely used in assistive shopping systems for reliable section identification and activation [2], [3].

2. Voice Command Interpretation

After initialization, the trolley prompts the user to speak the product category they want to visit. The microphone captures the audio input, and the Raspberry Pi performs speech recognition to extract the intended section name. Voice based interaction enables hands free operation, which is essential for users with visual impairment and has been validated in earlier assistive navigation systems [6].

3. Route Planning and Stepwise Guidance

When the destination section is identified, the trolley generates a movement plan using a grid representation of the store layout. The Raspberry Pi applies a Breadth First Search strategy to compute the shortest sequence of steps from the current position to the target cell. BFS is chosen because it guarantees minimal path length in uniform grid structures while keeping computation simple and efficient.

The Pi does not move autonomously but provides **step by step voice guidance** such as "move ahead," "turn left," or "turn right." This ensures the user stays fully aware of each movement direction. While the user follows the instructions, the Arduino continuously checks the ultrasonic sensor. If an obstacle is detected within a defined distance, the system pauses the next instruction and issues a warning. Ultrasonic sensing has proven effective for real time obstacle detection in indoor mobility applications [18].If the obstacle persists, the Raspberry Pi updates the grid by marking the blocked cell and recomputes a new BFS path before continuing.

4. Section Verification Using RFID

As the user approaches the expected shelf location, the trolley searches for the corresponding RFID tag placed at that section. When the tag is detected, the system confirms arrival through a voice message. This allows the user to confidently identify the correct aisle without relying on printed labels or visual cues. After confirmation, the system waits for the next voice instruction to either continue shopping or move toward the exit .

V. Implementation

The implementation of the intelligent shopping trolley combines hardware modules, software logic and controller coordination to create a functional assistive system for visually impaired users. The design follows a dual-controller approach in which the Raspberry Pi manages voice processing and navigation decisions, while the Arduino Uno handles sensor readings and RFID communication, a structure commonly used in lightweight IoT assistive systems [21], [22].

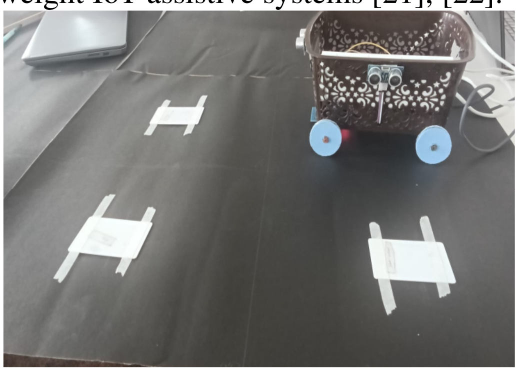

Fig. 3: Prototype implementation and testing environment of the IoT-Based Smart Trolley showing the assembled trolley with ultrasonic sensors, RFID tags on the path, and real-time navigation setup**.**

A.Hardware Integration

The prototype consists of a Raspberry Pi 4 for system control, a microphone and speaker pair for interacting with the user, an ultrasonic sensor for obstacle detection and an MFRC522 RFID reader for identifying section tags. RFID based identification has been reliably used in several shopping assistance models to support location confirmation [2], [3]. The Arduino Uno interfaces with both the ultrasonic sensor and the RFID module and sends processed values to the Raspberry Pi through serial communication. A buzzer connected to the Arduino provides immediate alerts when obstacles are detected, following established practices in ultrasonic based mobility systems [18].

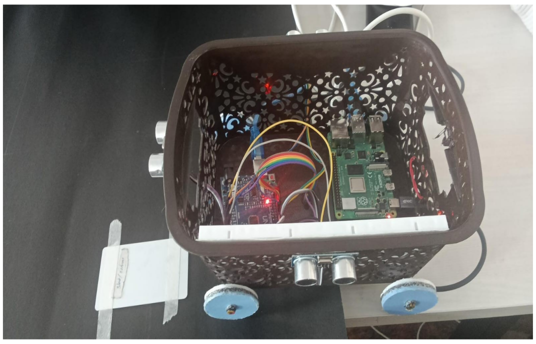

Fig.4: Hardware setup of the IoT-Based Smart Trolley showing integration of Raspberry Pi 3, ultrasonic sensors, RFID module, and speaker–microphone interface.

B. Software Framework

Python is used on the Raspberry Pi to implement voice recognition, text to speech output and BFS based route generation. The SpeechRecognition library interprets the user's spoken commands, similar to previous voice driven navigation systems for visually impaired users [6]. The Arduino is programmed using embedded C to continuously read data from the ultrasonic and RFID modules. All sensor values are transmitted to the Raspberry Pi via UART, where they are processed to update navigation steps or confirm section arrival.

C. Communication Between Controllers

Serial communication handled through PySerial enables real time data exchange between the Raspberry Pi and Arduino. The Arduino periodically sends obstacle distance readings and RFID tag IDs, while the Raspberry Pi responds with control keywords that indicate whether the system should continue guiding the user or pause due to an obstacle. This form of coordinated communication has been proven effective in IoT microcontroller integration tasks [22].

D. User Interaction Workflow

When the system is powered on, the user is greeted with an audio prompt and asked to speak the required section. Once the Raspberry Pi interprets the command, it issues stepwise voice instructions for movement. During navigation, the Arduino monitors the ultrasonic sensor and triggers an alert if an obstacle is detected. Ultrasonic sensing has shown reliable performance in indoor obstacle detection scenarios, making it suitable for visually impaired mobility needs [18]. When the trolley reaches the correct shelf tag, the RFID reader confirms the section and the system announces arrival.

E. Prototype Assembly

All hardware components are mounted on a stable trolley frame and powered using a portable battery pack. The prototype was evaluated in a controlled indoor environment with fixed aisles, RFID markers and dynamic obstacles to assess performance. The system's behavior was observed under different user commands and obstacle placements to verify practical usability.

VI. Result and Discusstion

The intelligent navigation trolley was evaluated in an indoor supermarket-like setup to determine how effectively it supports visually impaired users in locating product sections, avoiding obstacles and receiving spoken navigation assistance. The results reflect the performance of each functional module and demonstrate how navigation tasks as demonstrated in earlier studies [6].

The system responded in approximately 1.2 seconds, providing quick feedback and maintaining a smooth interaction flow.

1.Performance Metrics Overview

Figure.5 provides a summary of the key performance metrics obtained during testing. The Voice Command Recognition Accuracy was 93 percent, confirming reliable interpretation of spoken inputs across different users, consistent with prior

voice-enabled assistive systems [6]. The Obstacle Detection Reliability measured 92 to 93 percent, showing that the ultrasonic sensor successfully detected most nearby objects, a behaviour similar to established ultrasonic-based indoor mobility systems [18]. The trolley achieved a Section Identification Success Rate of 100 percent, demonstrating the stability of RFID based location mapping, as also evidenced in earlier assistive shopping solutions [2], [4]. The average Response Latency was 1.2 seconds, which aligns with typical processing delays observed in IoT controller communication and Python-based speech handling frameworks [7]. These combined metrics confirm that each core component of the system operates consistently and supports smooth interaction for visually impaired users

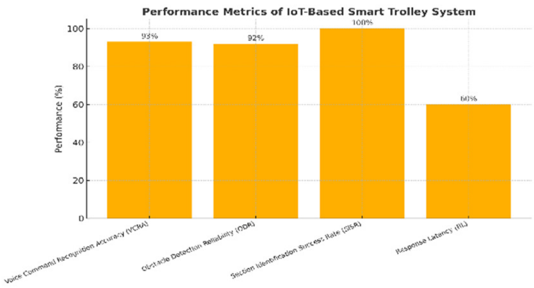

Fig.5 performance metrics

2.Voice Interaction Performance

Voice commands are the primary mode of communication for the user, making recognition accuracy essential. During testing, users spoke different section names such as *biscuits*, *rice* and *fruits*. The trolley correctly interpreted **93 percent** of all commands, confirming the effectiveness of speech-based control for visually impaired navigation tasks as demonstrated in earlier studies [6].

The system responded in approximately **1.2 seconds**, providing quick feedback and maintaining a smooth interaction flow.

3.Section Identification Using RFID

Each aisle was marked with an RFID tag, which the trolley used to confirm that the user had reached the correct section. Across all trials, the trolley achieved a 100 percent section identification success rate, matching the reliability reported in RFID-based assistive shopping solutions [2], [3].

Upon tag detection, the trolley played a spoken message (e.g. "You have reached the snacks section"), which **helped users** feel confident about their location.

4.Obstacle Detection and Safety

Obstacle detection was assessed using both static and moving objects placed at varying distances. The ultrasonic sensor achieved a 93 percent detection reliability, successfully identifying most obstacles in front of the trolley. This performance is consistent with ultrasonic-based indoor mobility systems used for visually impaired assistance [18]. Whenever the sensor detected an obstruction, the trolley paused further instructions and played an alert, preventing unintended collisions.

5.Navigation Behaviour and User Movement

The trolley guided users using stepwise voice instructions such as "move ahead" or "turn left." The internal BFS-based route selection allowed the trolley to choose the shortest available path. When obstacles blocked the intended path, the Raspberry Pi recalculated the route and continued guiding the user. This behaviour highlights the benefit of combining simple path planning with real-time sensing, which has also been emphasized in previous assistive navigation research [1], [5]. Users were able to reach the target sections without relying on external help, demonstrating the reliability of the system's navigation logic.

6. Combined User Experience

When all modules worked together, the trolley successfully guided participants from the entrance to selected sections and back to the exit. Feedback from test users indicated that:

- Voice messages were clear
- RFID confirmation increased confidence
- Obstacle alerts improved safety

These observations show that the system can meaningfully support independent movement for visually impaired shoppers and reduce dependence on human assistance.

VII. CONCLUSION

This paper presented the design and implementation of an IoT based intelligent navigation trolley developed to support visually impaired individuals during supermarket shopping. By integrating voice command recognition, RFID based section identification and ultrasonic obstacle detection, the system provides clear stepwise guidance and enhances user safety throughout the shopping process. The experimental evaluation demonstrated strong performance, achieving **93 percent voice**

recognition accuracy, **92–93 percent obstacle detection reliability**, **100 percent section identification success**, and an average **response latency of 1.2 seconds**. These results verify the stability and practical usability of the system in controlled indoor conditions, aligning with trends observed in earlier assistive navigation technologies [1], [6], [18].

Unlike traditional smart carts that focus mainly on automated billing or product scanning [2], [5], the proposed system emphasizes **mobility assistance**, **environmental awareness** and **independent navigation**, which are essential for visually impaired users. The combination of real-time sensing, responsive voice interaction and reliable section confirmation allows users to navigate aisles confidently without requiring continuous human support.

Overall, the system demonstrates that affordable IoT components and structured navigation logic can significantly improve accessibility in retail environments. With the integration of advanced mapping, autonomous motion and computer vision modules in future work, the trolley has the potential to evolve into a fully autonomous smart retail assistant capable of offering a more inclusive and efficient shopping experience for visually impaired customers.

VIII. Future Work

Future improvements can enhance the autonomy, intelligence and real-world adaptability of the system:

1.Store Pre-Mapping: Add an indoor premap feature similar to Google Maps so the trolley can load layouts of different supermarkets.

2.Assistive Call Button: Include an emergency/help button to notify nearby staff or guardians.

3.Motorized Movement: Integrate DC/servo motors to enable semi-autonomous or fully autonomous trolley motion.

4.Gesture Controls: Use short-range infrared or proximity sensors to support simple gesture-based navigation for users who prefer non-voice interaction.

5.Camera-Based Product Detection: Add an RGB camera with computer vision to identify products, check expiry dates and detect shelf availability.

6.Smart Inventory Feedback: Automatically report low stock or damaged items to store management for better inventory control.

These enhancements can transition the current prototype into a fully autonomous, AI-driven smart retail assistant.

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