Orientacart: Assistive Navigation Cart for the Visually Impaired Using RFID and Line Following

ANURAG P SHIRODKAR, ANAND M VERNEKAR, KARTHIK P, MOHAN V, VASANTH KUMAR REDDY G
ELECTRONICS AND COMMUNICATION ENGINEERING
AMRUTA INSTITUTE OF ENGINEERING & MANAGEMENT SCIENCES, BIDADI, BENGALURU -562109

ABSTRACT- The increasing demand for inclusive retail environments has highlighted the navigation challenges faced by visually impaired individuals in large supermarkets and shopping complexes. Existing smart-cart systems primarily focus on automated billing, product identification, or retail analytics, while neglecting mobility accessibility. This paper presents OrientaCart, a low-cost assistive following, radio-frequency identification (RFID) junction routing, and ultrasonic obstacle detection under an ESP32 controller. User commands are received via a Bluetooth-based Android application, and auditory guidance is provided by a DFPlayer Mini MP3 module that plays pre-recorded prompts through a 3 W speaker. The prototype was validated on a 10 m indoor track with four junction tags at a constant speed of 0.30 m/s, achieving 95% RFID tag-read accuracy and a mean obstacle-stop latency of 0.5 s. Compared with prior smart carts and mobile robots, OrientaCart offers an accessibility-first design, predictable behavior without camera-based perception, and a commercial bill of materials (BOM) below ₹6,500. The proposed hybrid protocol demonstrates that reliable assistive navigation can be achieved using embedded sensing and event-driven control, supporting scalable deployment in supermarkets and malls.

Index Terms—RFID, Assistive Navigation, Line Following Robot, Ultrasonic Obstacle Detection, ESP32, Inclusive Retail, Indoor Localization.

I. INTRODUCTION

Indoor mobility inside supermarkets is challenging for blind and low-vision shoppers. Conventional aids (such as a white cane or human escort) provide near-field obstacle awareness but do not support route planning, section-level localization, or junction-level decision-making. Meanwhile, many “smart cart” solutions emphasize checkout automation or retail analytics rather than mobility accessibility. Vision-based autonomy can address navigation, but it often increases cost, requires high processing power, and raises privacy concerns in public environments. Low-cost line-follower robots demonstrate reliable trajectory adherence on marked paths but typically lack contextual decision-making and global localization. Robotic obstacle avoidance systems using ultrasonic or laser sensors improve safety but still do not determine where to turn or how to confirm destination arrival. To close this gap, we present OrientaCart, a hybrid embedded system that integrates IR line tracking (for stability), RFID (for junction decisions and destination confirmation), and ultrasonic sensing (for active safety). All functions execute on an ESP32 microcontroller.

Contributions.

(i) A hybrid navigation protocol for marked indoor paths that couples IR path tracking with RFID-based junction logic; (ii) a complete assistive cart architecture with Bluetooth input and audio-first UX; (iii) a validated proto type with 95% RFID read accuracy and 0.5 s stop latency; (iv) comparative analysis against prior carts and robots; and (v) a commercialization path leveraging passive RFID and retrofittable hardware.

II. RELATED WORK

RFID-enabled carts streamline billing and inventory but assume a sighted user and visual interaction [1]–[3]. IR line following robots show stable path adherence with simple controllers but lack junction logic and user-facing accessibility [4]. Multi-sensor robots and fuzzy control methods enhance obstacle avoidance yet often incur higher compute and in tegration overheads for public deployment [5]. Recent work on smart carts explores path planning and store context, but still targets efficiency over inclusive navigation [6]. RFID infrastructure has also matured in transportation and transit systems, demonstrating robustness of tag–reader deployments in complex environments [7].

III. SYSTEM ARCHITECTURE BLOCK DIAGRAM AND FLOW CHART

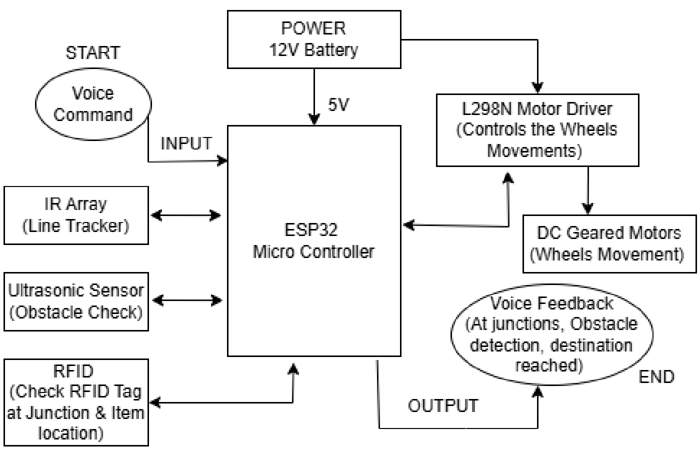

Figure 1: OrientaCart Block Diagram

The OrientaCart uses a modular embedded architecture centered on the **ESP32 Microcontroller (System Core)**.

Sensing and Input Layer: This layer gathers all environmental and user data:

- **IR Array (Line Tracker):** Detects the predefined black line path for directional control.
- **RFID RC522 Reader:** Scans tags for **junction decision-making** and **product identification**.
- **Ultrasonic Sensor:** Provides **real-time distance measurement** (Obstacle Check) to ensure safety.
- **Voice Command:** Initiates navigation goals via user input.

Actuation and Output Layer

This layer executes the control decisions:

- **L298N Motor Driver:** Controls the direction and power supplied to the **DC Geared Motors**, managing movement.
- **Voice Feedback:** The Speaker/DF Player Module provides **context-aware audio output** (directions, warnings, and destination confirmation).
- **Power Supply:** Provides the necessary **12V power** to all components.

TABLE - I
HARDWARECOMPONENTSANDROLES

Components	Description
ESP32	Main controller handling all inputs/logic.
IR Array Sensor	Detects the path to follow line
Ultrasonic Sensor	Avoids obstacles by measuring distance
RFID RC522	Used for junction navigation and product identification.
DFPlayer Mini + 3W Speaker	Plays voice feedback stored in microSD.
L293N Motor Driver	Drives and controls DC motor direction and speed.
2x 18650 Li-Ion Cells (7.4V)	Power source

A. HYBRID NAVIGATION PROTOCOL

The OrientaCart implements a Hybrid Navigation Protocol integrating optical, RFID, and ultrasonic sensing for robust indoor guidance[1].

1. Directional Stability and Localization

The default navigation loop maintains directional stability through IR-based tracking[2]. The cart follows a predefined path marked by a high-contrast line. Localization and routing decisions are governed by Radio-Frequency Identification (RFID)[3]. When the RC522 Reader detects an embedded tag, the unique identifier (UID) is matched against the current step in the pre-loaded navigation map[4]. If the match is successful, the corresponding action—such as executing a turn (left/right) or stopping—is executed[5].

2. Real-Time Safety Preemption

Safety is ensured by a dedicated Ultrasonic Preemption Routine. This routine continuously monitors the path ahead, and preempts motion whenever the measured distance (D) falls below a safe threshold (D_{safe})[6]. Upon halting, the system immediately plays a voice warning prompt ("Obstacle ahead, please wait")[7]. Motion automatically resumes once sufficient clearance is restored[8].

B. CONTROL LAW AND TASK TIMING

1. Differential Control Law

Path corrections are managed using a **Proportional-Derivative (PD) Control Law** applied differentially to the motors to maintain the line center. The line-offset error E is determined from a weighted reading of the IR sensor array. The differential PWM update Delta is calculated as:

$$\text{Delta} = K_p E + K_d (E - E_{prev})$$

Where K_p and K_d are the proportional and derivative gain constants, respectively, and E_{prev} is the previous offset error.

The Pulse Width Modulation (PWM) signals for the left PWML and right PWMR motors are then adjusted based on a constant base speed V_base to steer the cart back to the center

PWML = V_base + Delta quad and quad PWMR = V_base - Delta

2. Concurrent Task Timing

The entire system runs concurrently on the **ESP32 Microcontroller**[9], utilizing its dual-core architecture to handle time-critical tasks:

- **IR Loop:** Operates at a high frequency approx 100Hz for continuous, smooth line tracking.

- **Ultrasonic Polling:** Runs at 20–25Hz to ensure rapid, real-time safety checks.
- **RFID Reading:** Event-driven, triggered only when the cart enters a known tag zone.
- **BLE Parsing:** The Bluetooth Low Energy (BLE) communication for user commands is non-blocking to prevent interference with critical navigation routines.

TABLE - II

PIN MAPPING(REPRESENTATIVE)

Interface	ESP32 Pins / Notes
IR Array (5 ch.)	GPIO 26, 34, 35
L298N (ENA / IN1 / IN2)	GPIO 33,25,32
L298N (ENB / IN3 / IN4)	GPIO 14 / 12 / 13
Ultrasonic TRIG / ECHO	GPIO 27, 22
RC522 (SPI)	MOSI 23, MISO 19, SCK 18, SS 5, RST 2
DFPlayer Mini (UART)	TX/RX: GPIO 04/ 21

IV. EXPERIMENTAL RESULTS AND DISCUSSION

Tests were conducted on a 10-m indoor track containing four RFID junction tags. The cart maintained a constant speed of 0.30 m/s. We evaluated line tracking, RFID reading accuracy, obstacle-stop response, and overall usability.

Figure 2: AI Generated OrientaCart Prototype

A. Line Tracking and Junction Behavior

The cart successfully completed 19 out of 20 runs (95%). Average sideways deviation from the line was 2.3 cm, with slightly higher values at sharp turns. Junction turns were triggered only when the correct RFID tag matched the planned route.

B. RFID Accuracy vs. Reader Height

RFID performance depended on the RC522 sensor's height above floor tags. A clearance of 2–3 cm provided the most reliable reads while keeping enough ground clearance.

C. Obstacle-Stop Latency

With a 25 cm safety distance, the average motor stop delay was 0.50 s (range: 0.41–0.64 s). The distribution pattern is illustrated in Fig. 3.

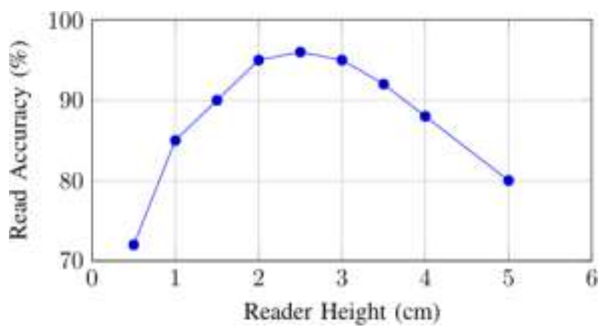

Figure 3: Place holder: RFID read accuracy vs. reader height over the tag.

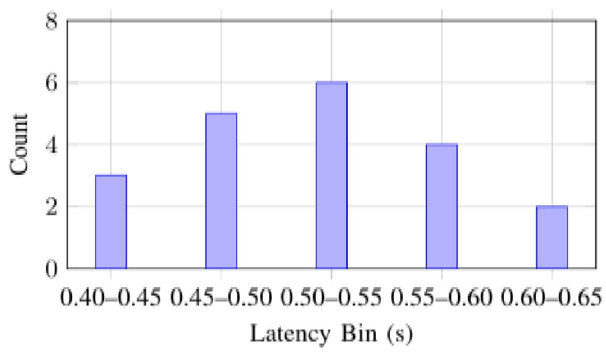

Figure 4 : Place holder: Obstacle-stop latency histogram(20trials).

D. Discussion

Reliability:
The 95% RFID read rate and consistent junction detection show that passive RFID tags are sufficient for reliable section-level navigation.

Safety:
The observed stop delays fall within acceptable limits for indoor operation at speeds up to 0.4 m/s.

Maintainability:
The system avoids cameras and cloud services, lowering complexity and reducing integration risks for retail deployment.

V. USER INTERACTION AND ASSISTIVE FEEDBACK SYSTEM

The user selects a destination through the Bluetooth app, after which the ESP32 loads the appropriate route and initiates IR-based navigation. Audio instructions are played using the DF Player Mini, which provides fast, clear playback of pre-recorded MP3 prompts.

A. Audio Prompt Set

Table III presents the list of audio prompts and their corresponding filenames.

B. Usability Assessment

Five participants, including two visually impaired users, tested the prototype. Their ratings (1–5 scale) and qualitative feedback are summarized in Table IV.

TABLE - III

AUDIO PROMPT MAPPING FOR DFPLAYER MINI

Event	File
System ready / startup	0001.mp3
Following path	0002.mp3
Turn left / turn right	0003.mp3 / 0004.mp3

Obstacle ahead, please wait	0005.mp3
Path clear, resuming	0006.mp3
Destination reached	0007.mp3

TABLE - IV

USABILITYFEED BACK (N=5)

Metric	Score
Prompt clarity	4.8
Ease of navigation	4.6
Confidence during operation	4.7
Overall satisfaction	4.7

VI. CONCLUSIONANDFUTUREWORK

We introduced OrientaCart, an assistive navigation cart that combines IR line tracking, RFID-based junction handling, and ultrasonic safety sensing under an ESP32 controller with an audio-first user experience. On a 10 m test track at 0.30 m/s, the prototype achieved 95% RFID accuracy and a 0.5 s average stop latency. The use of passive RFID tags, a BLE-based selection app, and DFPlayer audio output provides a practical and low-cost solution for inclusive retail navigation.

Commercialization: The retrofit-friendly architecture (BOM ≈ ₹6500) and minimal infrastructure requirements (floor tape and RFID tags) make the system suitable for pilot deployment in supermarkets and malls.

Future Work: Planned extensions include dynamic re-routing on tag grids, multi-cart coordination, cloud-linked shopping lists, onboard BMS telemetry, and optional on-device speech input.

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REFERENCES

[1] G. R. Kesava, S. S. K., V. K. Reddy, and S. Trivikram, “Smart shopping cart using radio frequency identification,” in *Proc. IEEE Int. Students’ Conf. on Electrical, Electronics and Computer Science (SCEECS)*, 2024.

[2] T. Arciuolo and A. Shakour Abuzneid, “Simultaneously shop, bag, and checkout (2SBC-Cart): A smart cart for expedited supermarket shopping,” in *Proc. Int. Conf. on Computational Science and Computational Intelligence (CSCI)*, 2019.

[3] S. V. Hove, A. All, and L. D. Marez, “Short on time? Context-aware shopping lists to the rescue: An experimental evaluation of a smart shopping cart,” in *Proc. 11th Int. Conf. on Quality of Multimedia Experience (QoMEX)*, 2019.

[4] S. S. Devi, S. Janani, M. U. Kavipriya, S. G. Kavyashree, and K. M. Chandrika, “Microcontroller-based line successor robot,” in *Proc. 5th Int. Conf. on Electronics and Sustainable Communication Systems (ICESC)*, 2024.

[5] X. Song, "Research and design of robot obstacle avoidance strategy based on multi-sensor and fuzzy control," in *Proc. IEEE 2nd Int. Conf. on Data Science and Computer Application (ICDSCA)*, 2022.

[6] R. Jain and P. Sharma, "Enhanced path planning for smart shopping carts," *IEEE Access*, vol. 13, pp. 11234–11245, 2025.

[7] A. Kumar and S. N. Rao, "RFID-based smart public transit system," in *Proc. Int. Conf. on Smart Transportation Systems*, 2023.

[8] Fithi Fessehatsion Ghebreamlak, Merry Zeray Semereab, Saron Bokretsion Ghebremichael, Ahed Abugabah, "Smart Shopping Application: Indoor Navigation System for Shops," 2024 15th Annual Undergraduate Research Conference on Applied Computing (URC), 2024.

[9] Alfian Ma'arif, Aninditya Anggari Nuryono, Iswanto, "Vision-Based Line Following Robot in Webots," 2020 FORTEI-International Conference on Electrical Engineering (FORTEI-ICEE), 2020.

[10] Narayan Jee, Sumit Kumar, Rajiv Ranjan Patel, Riman Mandal, Rahul Kumar Singh, Harsh Vardhan, "A Study of Speech Recognition and Emotional Intelligence," 2024 13th International Conference on System Modeling & Advancement in Research Trends (SMART), 2024.

[11] Balasaheb Jadhav, Pooja Wanjale, Renuka Gavli, Kaushalya Thopate, Niranjan Maharnawar, Nikhil Karmankar, "IoT Based Radar System using Ultrasonic Sensor for Enhanced Object Detection and Tracking," 2023 Global Conference on Information Technologies and Communications (GCITC), 2023.

[12] Pooja Garai, Aditya Nikam, Suyash Kerkar, Samruddhi Deshmukh, Atharva Mane, Suvarna Bhise, "Voice AI-Intelligence Based Voice Assistant," 2025 International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics (IITCEE), 2025.

[13] A. Naithani, T. S. Rajpal, V. Mistry, "TAV-Cart: Transaction Assistance and Validation Cart System for Effortless Shopping and Checkout," 2024 International Conference on Advances in Computing, Communication and Materials (ICACCM), 2024.

[14] S. Garlapati, A. Gupta, A. Dugad, S. Agarwal, and S. R., "Revolutionizing Shopping Experiences with Smart Carts," 2024 International Conference on Computing and Data Science (ICCDS), 2024.

[15] R. Akter et al., "RFID Based Smart Transportation System with Android Application," 2020 Second International Conference on Innovative Mechanisms for Industry Applications (ICIMIA), 2020.

[16] V. S. R. Bakka et al., "RFID Based Smart Public Transit System," 2023 4th International Conference on Electronics and Sustainable Communication Systems (ICESC), 2023.

[17] G. Kaur and G. Kamboj, "RFID Based Intelligent Transport System with RSU Communication for Emergency Vehicles in Urban Areas," 2022 4th International Conference on Inventive Research in Computing Applications (ICIRCA), 2022.