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The Book Cartographers

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Abstract: This project introduces an autonomous Library Assistant Robot designed to simplify book rack identification and navigation with in libraries. The robot follows a predefined line using a QTR- 8A sensor with PID control and detects rack positions through NFC tags placed along the path. A web dashboard allows users to select the desired rack, and the ESP32 microcontroller processes this command, enabling the robot to navigate, read NFC tag IDs, and stop precisely at the correct track. This system provides a reliable, low-cost, and efficient approach to library automation, minimizing manual search time and improving accessibility.
Index Terms: Line Following Robot, NFC, ESP32, Library Automation, PID Control, PN532, Autonomous Navigation.

I. INTRODUCTION

Modern libraries manage thousands of books distributed across multiple racks, making it difficult for users and staff to quickly locate specific sections. Manual searching consumes time and workforce, creating the need for a simple and automated retrieval system. Addressing this challenge, this project proposes an autonomous Library Assistant Robot capable of navigating predefined pathways and identifying rack locations using NFC technology. The robot follows a black-line track laid on the library floor using a QTR-8A IR sensor array. A PID (Proportional–Integral–Derivative) algorithm ensures smooth, stable, and accurate line tracking. To identify rack positions. NFC tags labeled with IDs such as R1, R2, R3, and R4 are placed directly on the path. A PN532 NFC reader mounted at the bottom of the robot scans these tags as it moves. When the robot detects a tag who's ID matches the one selected by the user on a web dashboard, it stops precisely at that location. The ESP32 microcontroller forms the core of the system, combining motor control, NFC communication, and Wi-Fi connectivity. Through a dashboard interface, users can remotely choose the desired rack, after which the robot autonomously navigates and identifies the target. By merging autonomous navigation, real-time sensing, and IoT-based command control, this project provides a cost-effective and scalable solution for library automation. Its simplicity, accuracy, and reliability make it suitable not only for book management but also for various guided robotic applications in warehouses, educational labs, and indoor logistics.

II. LITERATURE SURVEY

A. RFID-Based Library Management System With Android Mobile Access Application

In [1], the authors propose an RFID-based library management system integrated with an Android application to automate issuing, returning, and tracking of books. The system uses RFID tagging, RAD methodology, and FURPS evaluation for performance.

Methods Used:

- RFID tagging of books and users
- Android mobile application frontend
- Rapid Application Development (RAD) model
- System modeling with use-case, context, and access diagrams
- FURPS evaluation (Functionality, Usability, Reliability, Performance, Security)

Advantages:

- Faster book issuing and returning
- Accurate book tracking

- Android app improves accessibility
- Reduces manual searching effort

Limitations:

- Only Android supported (noiOS)
- Some browser and UI compatibility issues

B. Mobile Robot Capable of Crossing Floors for Library Management

In [2], the authors propose a mobile robot capable of crossing floors in libraries to automate book searching and transportation. The robot uses a custom floor- crossing mechanism, IR/ultrasonic sensors, and RFID/barcode scanning.

Methods Used:

- Custom floor-crossing mechanical module
- Sensors: ultrasonic/IR for obstacle detection
- RFID or barcode scanning
- Pre-mapped navigation paths
- Microcontroller-based control and path planning

Advantages:

- Works efficiently across multiple floors
- Reduces staff workload
- Accurate book detection

Limitations:

- Mechanically complex, higher cost
- Requires precise mapped layout

C. Design and Implementation of Library Management Robotic System

In [3], the authors propose a robotic system that automates issuing and returning of books using line following, barcode detection, and a robotic arm controlled via Raspberry Pi and Python GUI.

Methods Used:

- Line-following navigation
- Barcode detection + image processing
- Robotic arm (horizontal & vertical motion)
- GUI in Python (Tkinter)
- Wi-Fi communication with RaspberryPi4
- Mongo DB database

Advantages:

- Fully automates issuing and returning
- Real-time database updates
- Reduces human involvement significantly

Limitations:

- High hardware cost
- Barcode-based system fails if labels are damaged
- Line-following is path-dependent

D. IoT-Based Library Management Automation System Using RFID

In [4], the authors propose an IoT-based library automation system that integrates RFID technology with cloud connectivity to manage book borrowing, returning, and anti-theft operations. The system places RFID tags on books and user IDs, and uses an RFID gate to identify unauthorized removals. A cloud backend updates book status in real time and also provides users with book suggestions and availability information.

Methods Used:

- RFID tagging on books & user cards
- Cloud backend for real-time updates
- Security gate for anti-theft
- User terminal for scanning books and IDs

Advantages:

- Automates borrowing and returning
- Reduces librarian workload
- Provides anti-theft detection
- Suggests related books

Limitations:

- High installation cost
- Requires stable internet
- Tags become useless if damaged

E. IoT Book Bot (2022)

In [5], the authors propose the IoT Book Bot, a semiautonomous robotic system designed to minimize overdue returns by collecting books from students and transporting them back to the library.

The system uses a Raspberry Pi with a camera for QR/barcode scanning, a NodeMCU (ESP8266) for IoT connectivity via the Blynk app, and a load sensor to detect book placement. All book and user data are stored in a cloud database (MongoDB), enabling remote monitoring of returns.

Methods Used:

- Raspberry Pi+Pi camera
- Node MCUESP8266+Blynkapp
- QR & Barcode scanning
- Load sensor to detect book intake(max5kg)
- Mongo DB database

Advantages:

- Encourages timely book returns
- Automates major book return processes
- High accuracy in book/user recognition

Limitations:

- Requires internet for Blynk
- Bot is not fully autonomous
- Hardware setup & maintenance complexity

F. Limitless: A Mobile Application Featuring Next- Generation Library Facilities

In [6], the authors propose Limitless, a next-generation mobile application designed to unify and streamline modern library services across multiple universities. The system integrates features such as book search, inter-library access, digital reading materials, room reservation, online payments, and complaint management. The authors validated the system through a user survey involving 40 students, demonstrating the need for a centralized platform that reduces the time and effort spent navigating different library systems. The application aims to modernize library interactions by combining all essential services into a single, user-friendly mobile interface.

Methods Used:

- Unified mobile application
- Usersurveywith40students(feedback- driven design)
- Cross-library membership system

Advantages:

- Access to multiple university libraries
- Saves user time and cost
- Offers room booking, payments, donations, complaints

Limitations:

- No advanced tracking/recommendation features
- Requires stable internet
- Security improvements needed

III. METHODOLOGY

The proposed system operates through four integrated stages. First, the user selects the required rack ID from a web dashboard, and the ESP32 receives this command via Wi-Fi. Next, the robot navigates along a predefined black line using a QTR-8AIR sensor array and PID control to ensure accurate and stable movement. As it moves, the PN532 NFC module continuously scans tags placed on the floor at each rack location. When the detected NFC tag matches the targe track ID, the ESP32 immediately stops the robot at the corresponding rack and optionally sends a status update back to the dashboard. The hardware modules motors, sensors, NFC reader, and communication unit operate in coordination under theESP32'scontrol.Thismodulardesignensureseasy system expansion and reliable real-time performance.

A. System Architecture

The system block diagram shows how the ESP32 microcontroller receives the target rack ID from the web dashboard and simultaneously processes inputs from the line sensor and PN532NFC reader. Based on these inputs, the ESP32 sends PWM and direction signals to the TB6612 motor driver, which controls the DC motors for navigation. The entire robot is powered by a Li-ion battery with a buck converter, enabling stable operation of all modules.

B. System Requirements

The hardware components used in the system include:

- ESP32 Development Board–Controls motors, sensors, and Wi-Fi.
- QTR-8AIR Sensor Array – Detects the line for navigation.
- PN532NFC Module – Reads NFC tags placed on the floor.
- NFC Tags (NTAG213/215/216) – Represent rack IDs (R1, R2, R3…).
- TB6612FNG Motor Driver –Drives the left and right motors.
- 2×DC Gear Motors (150–300RPM)– Provide robot movement.
- Chassis, wheels, caster wheel–Physical body and movement support.
- Li-ion7.4V Battery–Main power source.
- DC-DC Buck Converter (5V)– Converts battery voltage for electronics.
- LEDs, buzzer, switches, wiring – Indicators and basic connections.

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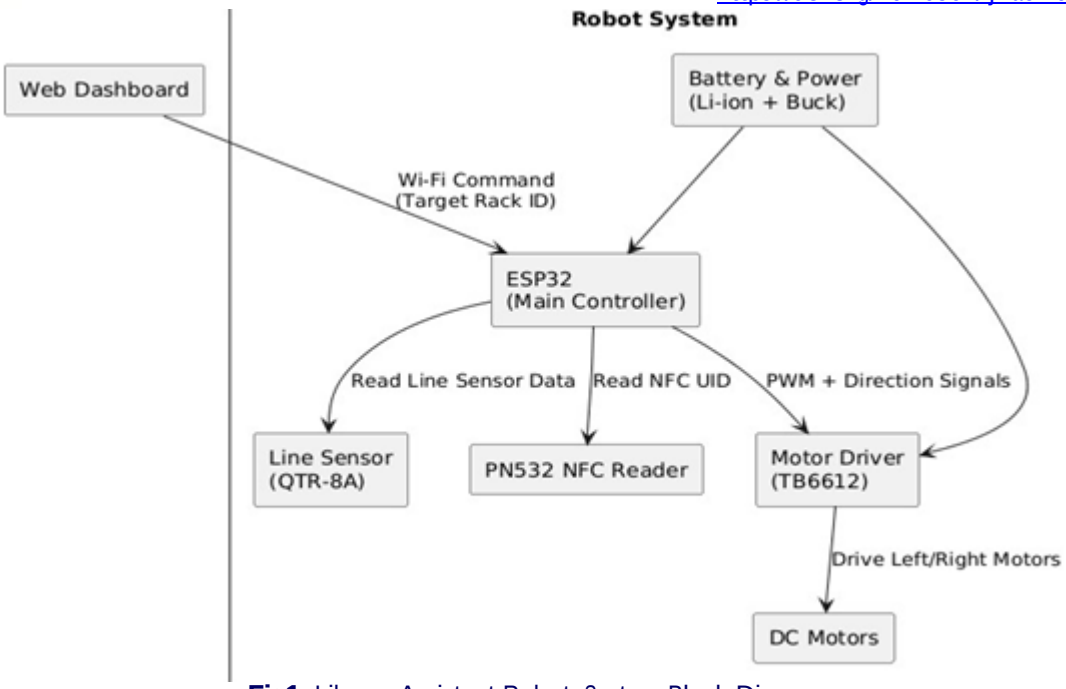

Fig1. Library Assistant Robot–System Block Diagram

The software components used are:

- ESP32 Firmware –Main controller program.
- Line-Following Module (PID)–Controls motor speed based on sensor error.
- Wi-Fi Communication Module–Receives rack ID from dashboard.
- Web Dash board Interface - Allows user to select the rack/book.
- NFC Reading Module – Reads tag UID and checks rack ID.

C. Functional Requirements

- Line following using IR sensor
- NFC tag detection
- Rack ID comparison
- Robot stopping at correct rack
- Dashboard-to-robot command transfer

D. Non-Functional Requirements

- High accuracy(1–2cmNFCdetection)
- Reliable operation
- Low cost
- Expandable rack / tag system

E. Prototype

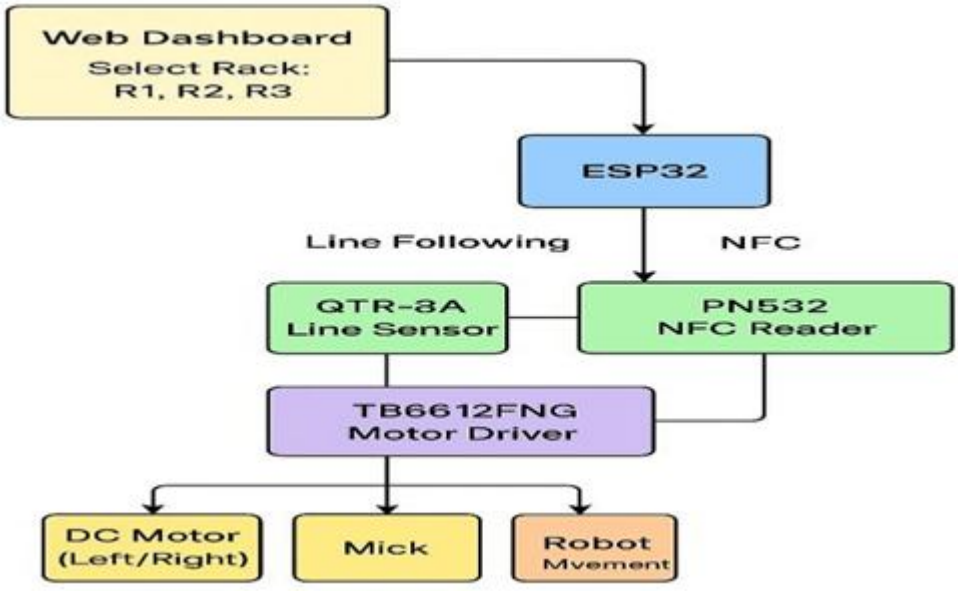

Fig 2. Prototype Architecture of the Library Navigation Robot

The prototype diagram shows how the Library Assistant Robot works. The user selects a rack (R1, R2,R3…) from the web dash board, and this command is sent to the ESP32 controller through Wi-Fi. The ESP32 controls two main systems: the QTR-8A line sensor for navigation and the PN532 NFC reader for detecting rack tags. The sensor outputs are processed by the ESP32, which then drives the TB6612FNG motor driver to control the left and right DC motors.

F. Working Principle

The Library Management System integrates a digital book management platform with an autonomous Library Assistant Robot to simplify book search and retrieval. The system consists of two digital interfaces the Student Portal and the Admin Portal along with a physical robot that navigates the library to locate racks using line-following and NFC technology.

- In the Student Portal, users log in with their credentials and can search for books, check availability, view rack numbers, and request books. All the student's activities such as book issue history, due dates, and fines are also displayed within the portal. When a student requests a book, the rack number associated with that book is stored and passed into the system workflow for further processing.
- Through the Admin Portal, the librarian manages the entire library database. The admin adds new books; updates details, assigns rack numbers, and oversees issue or return operations. When students request books, the admin reviews the request and may trigger the robot to assist in locating the rack. The admin interface also monitors system activity, inventory status, and student usage patterns.
- The Library Assistant Robot functions as the physical automation part of the system. Once the admin or system sends a rack ID to the robot through Wi-Fi, the robot begins its operation. It follows a black guideline on the floor using a QTR-8A line sensor and continuously scans for NFC tags placed at each rack location with a PN532NFC reader. Every rack (R1,R2,R3…) has a unique NFC tag. As the robot moves, it compares each scanned tag with the target rack ID. When the correct tag is detected, the robot immediately stops at that rack, indicating that the requested location has been reached.
- System Integration and Communication: All system modules are interconnected through a centralized workflow, where the Student Portal, Admin Portal, and Library Assistant Robot communicate in real time via Wi-Fi. This integration ensures synchronized data exchange, accurate rack identification, timely robot activation, and consistent updates across the entire library management system.
- Overall, the system combines software- based book management with robot-based physical navigation to create a seamless library experience. The portals handle all digital record-keeping, user management, and book transactions, while the robot ensures accurate and automated rack identification within the library. It reduces manual workload, minimizes human error.

G. Results

The developed Library Assistant Robot successfully followed the predefined line path using the QTR-8A sensor and maintained stable navigation with the PID control algorithm, which minimized deviations and ensured smooth movement along complex trajectories. The PN532NFC reader accurately detected NFC tags placed at each rack location within arrange of 1–2cm, providing precise rack identification and minimizing errors during retrieval operations.

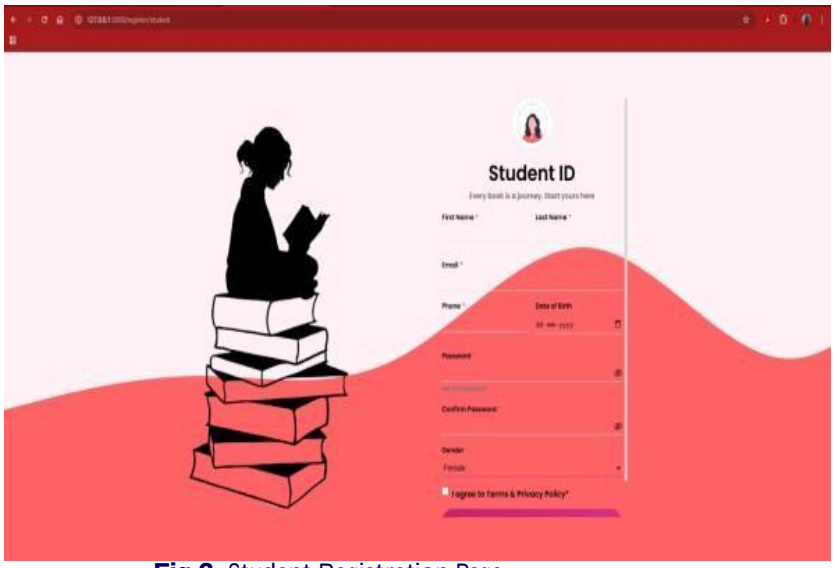

Fig 3. Student Registration Page

The robot consistently stopped at the correct rack when the scanned NFC tag matched the target rack ID sent from the web dash board, demonstrating reliable integration between hardware and software components. The Student and Admin Portals operated seamlessly, enabling real-time book searches, request handling, and database updates. Students could efficiently locate books and place requests, while administrators could monitor inventory, approve requests, and maintain the database. Integration of the robot with the portals ensured that physical book movements and digital records were synchronized, reducing manual effort and potential human errors. In repeated tests, the system showed high reliability, completing multiple retrieval and placement tasks without deviation normal function.

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The combination of autonomous navigation, NFC-based rack identification, and web-based management proved effective in optimizing library operations. User feedback indicated that the interface was intuitive, and the robot's responsiveness improved overall operational efficiency. Overall, the system not only demonstrated technical robustness in autonomous navigation and precise rack targeting but also highlighted the potential for scalable deployment in medium to large libraries, significantly reducing time and effort in book management. In order to create secure account, students must enter personal information like name, email address, phone number, date of birth, password, and gender on the Student Registration page, which is shown in this screenshot.

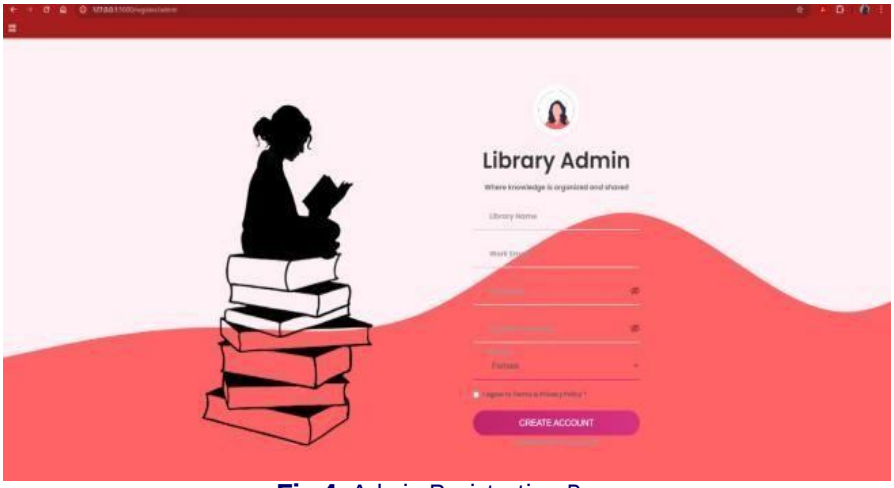

Fig 4. Admin Registration Page

In order to ensure safe admin on boarding, this screenshot shows the Admin Registration interface, which enables administrators to create an account by providing library details, email, password, and gender.

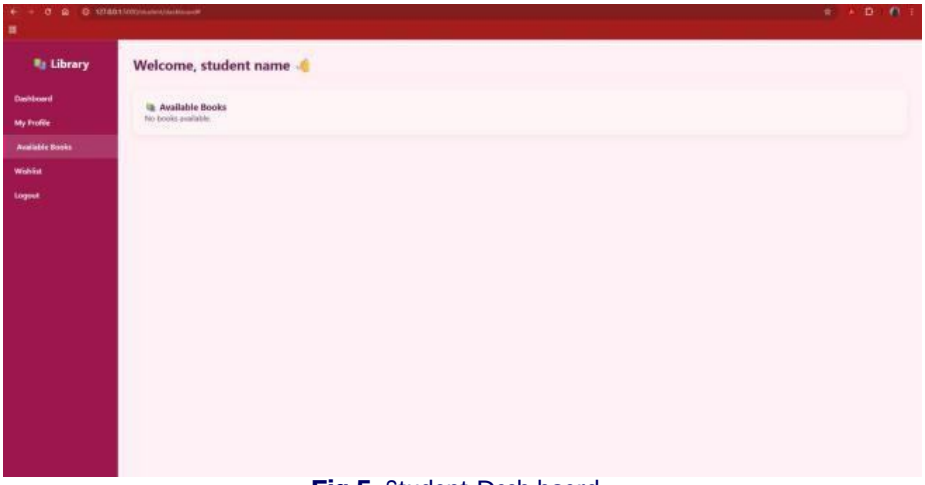

Fig 5. Student Dash board

The Student Dashboard, which allows logged-in students to view available books, access their profile, manage wish lists, and easily navigate the system through an intuitive interface, is depicted in this screenshot.

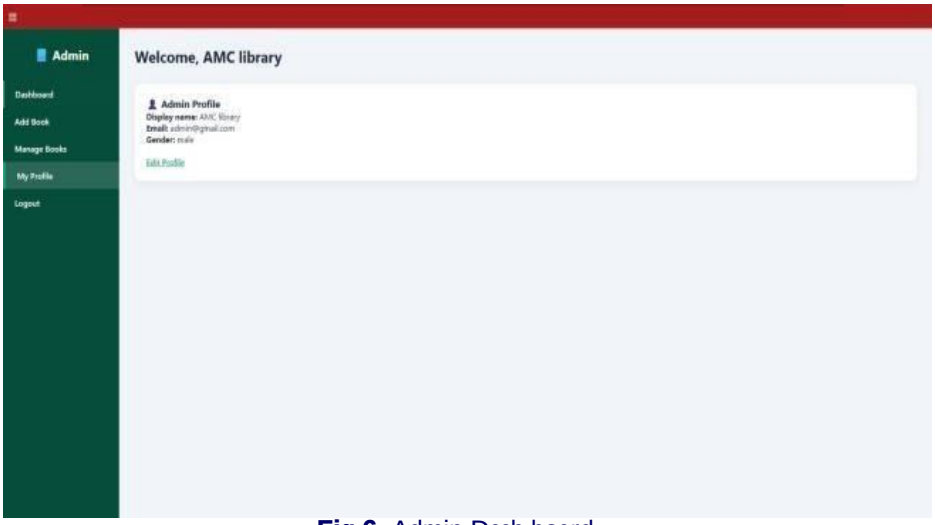

Fig 6. Admin Dash board

The Admin Dash board is displayed in this screenshot following a successful login. In order to ensure efficient library administration, it offers options for adding books, managing book records, and viewing or editing the admin profile. It also enables administrators to view the activities of the system and thus control library data in a centralized manner. The dashboard offers an interface that facilitates easy navigation and updating through reducing efforts in library management.

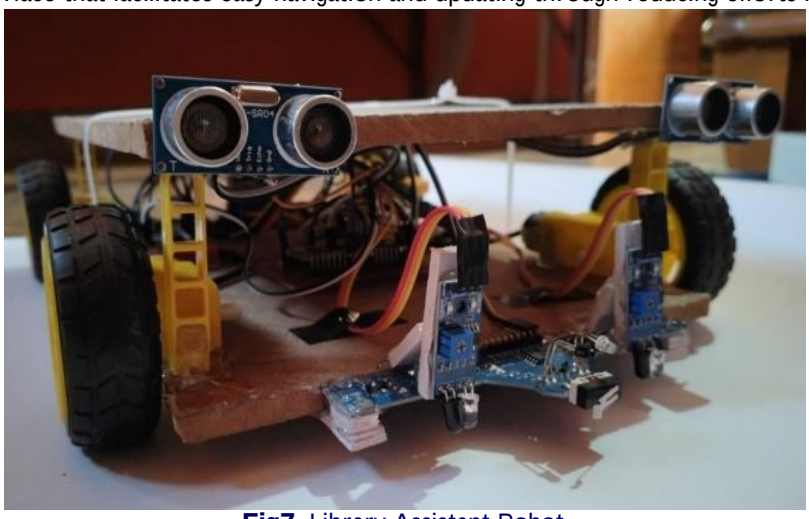

Fig7. Library Assistant Robot

The image shows the prototype of a Library Assistant Robot designed for indoor navigation. It follows predefined paths using sensors and stops at the correct book rack using NFC identification. The system communicates with a user interface to guide users efficiently to the required book location.

H. Conclusion

The integrated library automation system, combining Student and Admin Portals with a line-following NFC- enabled robot, provides an efficient and practical solution for modern library management. The digital portals simplify book search, issue, return, and record- keeping, while the robot ensures accurate physical assistance in locating racks. By merging software management with autonomous hardware operation, the system reduces manual effort, improves accuracy, and demonstrating that simple sensors, and web technologies can create a reliable and cost-effective library solution. This project also highlights the potential for expanding library automation to include features such as real- time inventory tracking, automated notifications, integration of robotics with web-based management lays a strong foundation for future enhancements, making libraries more organized, technologically advanced, and user-friendly, and showcasing the value of combining hardware and software for practical real-world applications. It also paves the way for smarter, more efficient, and fully automated library systems in the future. This approach demonstrates how technology can significantly enhance efficiency and user experience in everyday library operations.

I. Future Work

- Integration of a Robotic Arm: Adding a pickup-and-drop arm to enable complete automated book retrieval and placing, eliminating human intervention by automating the pickup and placement of books.
- Advanced Obstacle Detection: Using LiDAR, ultrasonic sensors, or depth cameras for intelligent navigation and safe movement in dynamic library environments.
- Enhanced Security & Authentication: Implementing biometric or multi-factor login systems in student and admin portals for data protection and secure access.
- Auto-Charging Docking System: Implementing a smart charging station that allows the robot to autonomously return and recharge when battery levels are low, ensuring uninterrupted library operations.
- Multi-Robot Coordination: Deploying multiple robots to work together for faster book retrieval and improved efficiency.
- Mobile Application Development: Creating Android/iOS apps for easier access to student and admin functionalities, including book search, requests, and notifications.
- Cloud-Based Database & Analytics: Migrating library data to cloud servers to ensure scalability, secure backups, andreal- time analytics for usage trends.
- Voice-Controlled Interface: Allowing students and admins to interact with the system and robot through voice commands for more accessibility.
- Multi-Robot Coordination: Deploying multiple robots that communicate and work together to handle high-demand book retrieval tasks in large libraries.
- Machine Learning for Navigation: Training the robot to adapt to path changes, predict movement, and improve line-following and tag detection accuracy over time.

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