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Library Management Robot with Line Following Navigation and RFID Based Book Identification

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Abstract **- The work presents an autonomous robot that simplifies library book retrieval. The system incorporates precise navigation mechanisms, a robotic arm, and RFID-based book identification. The robot moves precisely in the direction of the assigned bookshelf by following a predetermined path using a line-following system based on infrared (IR) sensors. The central component of the system is the ESP32 microcontroller, which processes sensor data in real time, manages motors, and enables communication with a mobile application. The robotic arm's RFID reader ensures precise selection by confirming the book's identity prior to retrieval. With the help of servo motors and a gripper mechanism, the robotic arm carefully handles books to avoid damage. Users can search for books and request their retrieval through a mobile application. By combining automation with user-friendly interaction, the library management robot , LMR enhances operational efficiency, reduces manual workload, and offers a scalable solution for modernizing library management.**

Keywords: **RFID;LMR;IR;ESP32;DC;IDE;MIT; PWM ;LCD ;IoT ;WiFi ;UI ;H-Bridge**

I. INTRODUCTION

Libraries are hubs of valuable information resources, large numbers of print and electronic books and journals and other media. Library functions that include book search and return create high amounts of manual effort, which is also prone to human error in the attempt to reduce it. As a result, the books could still be lost, the search time could be extended and the quality of the user experience could be degraded. With the increasing scale and complexity of libraries, automation is more critical to improve efficiency.

Over the years, numerous research studies have investigated the role of robotic automation in library management to enhance book retrieval and organization. According to [1], a library book management robot was developed based on RFID technology and a robotic gripper for the automatic placement and retrieval of books. Similarly, [2] proposed an autonomous robot that tries to navigate predefined paths to fetch books on request from the web-based system, ensuring proper processes of issuing and returning books. Subsequent development in [3] incorporated IoT-based user interfaces, enabling users to remotely search for books while the robot autonomously copies them. Meanwhile, [4] developed a library assistant robot with line-following navigation and RFID scanning for the fast and more efficient location and transportation of books. The work [5], was more focused on the mechanical and electronic design aspects of robotic library automation hence realizes the combination of servo motors, RFID readers, and real-time navigation systems to enhance book handling. Despite these technological advancements, traditional library management systems still suffer from major limitations. Manual book retrieval and return processes are not only time-consuming but also prone to human errors such as book misplacement, inaccurate record-keeping, and inefficient inventory tracking.

This paper introduces an autonomous library robot designed to optimize book retrieval in libraries. By incorporating a

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robotic arm, RFID technology and precise navigation mechanisms, the system enhances efficiency and minimizes manual effort in library operations. The robot is controlled by an ESP32 microcontroller, ensuring smooth interaction with a mobile application. In Section II, the proposed system is outlined, followed by the methodology in Section III. Section IV details the implementation, while Section V discusses the results and analysis of the system's performance.

II. PROPOSED SYSTEM

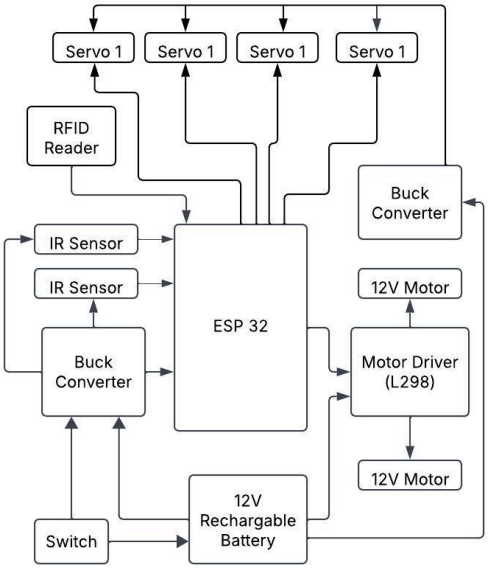

Fig.1. Block Diagram of Library Management Robot

The proposed system is an independent LMR aimed at streamlining and automating the retrieval of books. The robot combines a number of primary components: a robotic arm, RFID book identification, a navigation system, and a communication interface with a mobile app. The primary goal of the system is to enhance the efficiency of finding and retrieving books in a library environment, minimizing human labour and error in the process.

i. Navigation System
The robot travels in a pre-set path along the library via an infrared (IR) sensor-based line-following system. This guarantees that the robot travels in a precise, straight line towards the destination bookshelf. The IR sensors sense the lines on the ground, directing the robot along a defined path for precise movement within the dynamic space of a library. Navigation for the robot is completely automated and does not require human interaction during the retrieval of books.

ii. RFID based book identification
The RFID reader is attached to the robotic arm, allowing the system to read the RFID tags attatched to the books. As the robot approaches the appropriate shelf, the RFID reader checks the identity of the book ordered by the user. This process allows only the appropriate book to be picked from the shelf with fewer errors. The application of RFID technology enables fast, accurate, and reliable identification, without manual scanning or handling of every book by a librarian each time.

iii. Robotic arm and gripper mechanism
After the RFID system identifies the right book, the robotic arm, driven by four servo motors, gently lifts the book. The arm has a gripper system, which gently takes the book to avoid causing any damage in the process of retrieval. Precision and agility of the arm are important to avoid damaging the books while retrieving them and also not disturbing the neighbouring books on the shelf.

iv. ESP32 microcontroller and system control
The ESP32 microcontroller is the central processing unit of the system, managing the real-time processing of sensor data, motor control, and communication with the mobile app. The ESP32 enables smooth interaction between the robot sensors, the motorized units, and the user interface, enabling smooth and synchronized operation of the entire system. Its strong communication feature makes it possible for the robot to receive instructions, monitor its position, and provide updates to the user in real-time.

v. Mobile application interface
The mobile app, created with MIT App Inventor, is the user interface of the system. Users are able to search for books, ask for retrieval, and monitor the movement of the robot inside the library. The app offers an easy and user-friendly means for library users to interact with the robot, improving the user experience and enabling remote monitoring of the book retrieval process.
This system combines automation with easy-to-use technology to automate library operations. By reducing the amount of human intervention in retrieving books, it makes library operations more efficient and less prone to errors, offering a contemporary and scalable solution for library management.

III. METHODOLOGY

The designed Library Management Robot LMR is an independent system that seeks and fetches books from a library according to the input from users. The methodology is followed in a sequential manner as illustrated below.

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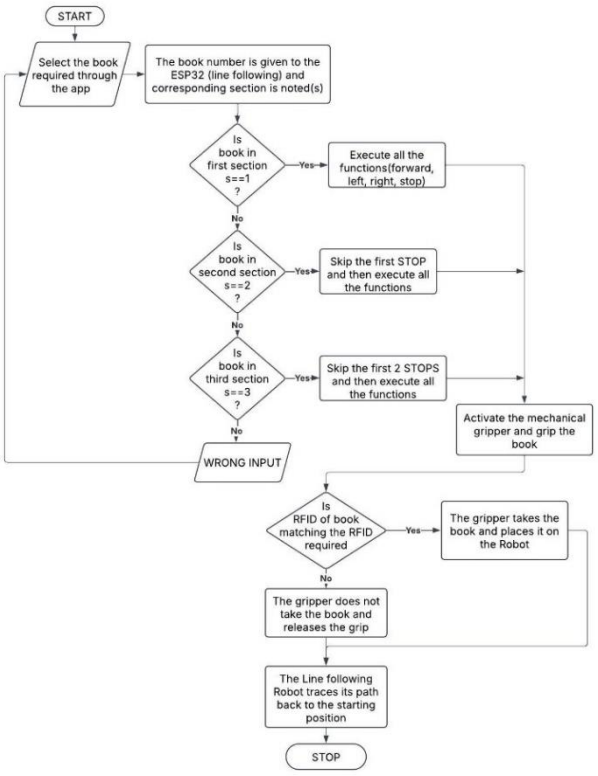

Fig.2. Flowchart of Library Management Robot

This system starts by taking the book ID input from a user via a mobile app. The input is processed and the corresponding section of the book is passed to the microcontroller. The book is divided into pre-defined sections: Section 1, Section 2, and Section 3. In case the book does not appear in any of these sections, the system identifies the input as invalid and ends the fetching process. After the location of the book is determined, the robot starts navigating through a pre-programmed line-following path. Depending on the section of the book, the robot changes its movement. In Section 1, it executes all normal movements, whereas in Section 2, it does not make the first stop. For Section 3, the robot does not make the first two stops before executing the rest of the movement functions to get to the right shelf.

When it gets to the assigned section, the robot checks the identity of the book using an RFID reader by comparing the RFID tag with the given book ID. If there is a match, the robot picks the book using its gripper and places it on the robot. If there is no match, the robot does not pick the book. The robot comes back the same way to hand it over to the user. In case the book is not found, the system notifies the user with a "BOOK NOT FOUND" message. This methodological process facilitates effective book identification, navigation, and retrieval while reducing errors and optimizing the robot's movement in the library.

IV. IMPLEMETATION

The Library Management Robot (LMR) functions as a standalone device that automates the retrieval and return of books in libraries. It implements robotics, RFID technology, and advanced navigation methods to achieve accuracy and efficiency. The entire system is maintained by an ESP32 microcontroller which processes information received from the sensors, controls the motors, and verifies which book is being returned. The robot follows a pre-mapped line to the book's location. Infrared (IR) sensors detect black guide lines situated on the floor of the library. The received information is processed in real-time by the ESP32 unit. This information can be used to control speed and the angle of rotation to achieve precise movements. The robot efficiently navigates through the library with the aid of two DC motors and L298N motor driver that provide the robot with the ability to smoothly accelerate, decelerate, and turn while driving to the designated shelf.

When the correct bookshelf is approached, RFID technology is applied by the robot to recognize the book. All books are integrated with a dedicated RFID tag, which has a UID. An RFID reader placed on the robot arm reads the tag and authenticates it to the book query issued through the mobile app. Upon matching of the UID, the gripper of the robot arm shown in Fig. 3 is moved to pick the book safely. The arm, driven by four servo motors, offers multi-axis movement, such as upward and downward movement and rotation. The gripper, having a soft rubberized surface, will hold the book securely without damage. The process of retrieval is fully automated and free from human error like misplacement of the book and slowness.

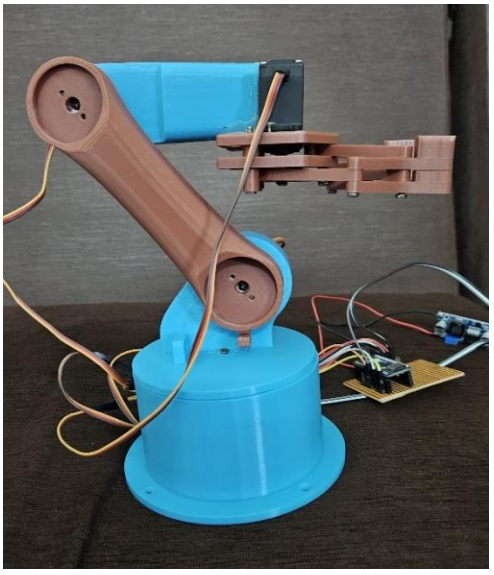

Fig.3. Mechanical gripper (side view)

The power system is configured to deliver a constant and reliable power supply for extended operation. A 12V rechargeable battery powers the robot, and power to sensitive components like the ESP32, IR sensors, RFID module, and

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servo motors is regulated by a buck converter. Power-saving mode saves the robot operation time, making it perfectly fitted for a busy library environment. The incorporation of automated guidance, RFID-tag-based book identification, and accurate control of the robotic arm allows the LMR to be a stand-alone system for simplifying book return and retrieval processes in contemporary libraries.

The ESP32 microcontroller is run through the Arduino IDE, where it processes sensor data, powers the robot's motors, and communicates with the mobile application via Wi-Fi. The microcontroller performs book requests, navigates through the IR sensors, authenticates books through RFID, and powers the robotic arm. It also provides a Wi-Fi connection to communicate with the mobile application to allow the robot to receive requests and send updates on its execution. Two IR sensors control the movement of the robot, identifying variations in color between the black lines and the white ground and maintaining the robot on the path. An RFID reader confirms the retrieval of the appropriate book by reading the RFID tag and comparing it with the book ID requested. If matched, four servo motors are used to control the robotic arm for accurate gripping and lifting. The L298N driver-controlled DC motors allow precise movement and direction change, making the system very efficient and reliable

V. RESULTS AND DISCUSSION

The LMR proved effective in integrating RFID, line-following navigation, a robotic arm with a gripper, and the ESP32 microcontroller to facilitate automated book retrieval from libraries. The system was effective, with the ESP32 efficiently handling user input, movement of the robot, and RFID authentication in real-time. Navigation was accurate using the line-following approach, though minor tuning of sensor sensitivity was required when surfaces were shiny or rough. The 3D-printed gripper performed optimally on average-sized books but had difficulty with very thin or heavy books. The RFID technology was highly accurate, resulting in the return of the correct book only. In spite of these issues, the robot was able to successfully conduct book pick-up and delivery automatically, minimizing human interaction.

The arm of the robot, driven by four servo motors, was used to pick up and set down books. It was equipped with a basic 3D-printed gripper that was able to grip most books securely. In testing, the gripper handled standard-sized books well, but had a bit of trouble with books that were too thin or too heavy. Although the design was functional and light, changes like a higher gripping force or a more flexible gripper would make it more useful for a greater range of book sizes. Each library book was labeled with an RFID tag with a unique ID. The RFID reader of the robot, attached to the robotic arm, read these tags to verify if it was the right book ordered by the user. The RFID matching was very precise and made sure only the right book was transferred. No mismatches were noted when the tests were conducted, so this aspect of the system is one of the most reliable.

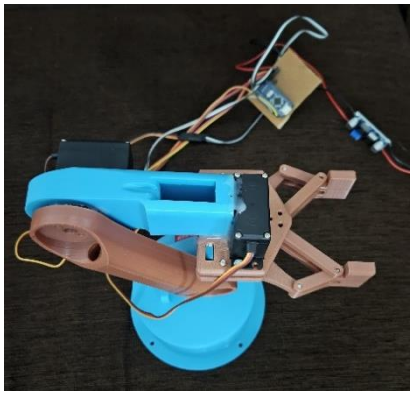

Fig. 4. Gripper (Top view)

In order to navigate, the robot used black lines on the floor and followed them with infrared (IR) sensors. The line following was effective and guided the robot through correct sections by bypassing lines depending on the input. It accurately moved to the correct shelves. When navigating through shiny or rough floors, sometimes the sensors provided inconsistent data, and adjustments in sensitivity were needed. Still, navigation was consistent for indoor library environments.

Fig.4. Line Following and different sections

One of the best things about the system was the seamless integration between the mobile app and the robot. Users were able to easily pick the book they required using the app. After the request was placed, the robot commenced work. This was a user-friendly system that allowed anyone to use the system even without technical background. The robot and app exchanged information via Wi-Fi, which was fast and efficient in tests.

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Fig. 5. Mobile application screen

The Library Management Robot successfully combined RFID, line-following sensors, Wi-Fi, and a robotic arm to automate book retrieval and reduce manual work. While minor issues like limited grip range, RFID positioning, and power limits were observed, the system still performed well. Future improvements such as better gripper design, AI-based navigation, and smarter power systems can make it more efficient for real-world use in libraries.

VI. CONCLUSION

The Library Management Robot LMR is an advanced automation system developed to streamline library operations by reducing the need for manual work. It utilizes technologies like RFID for accurate book identification, infrared sensors for line-following navigation, and a servo-controlled gripper to handle books efficiently. An ESP32 microcontroller manages the system and connects with a custom mobile application, enabling users to request books remotely. During testing, the robot effectively identified, located, and delivered books, showcasing reliable performance. Some limitations such as grip challenges with varying book sizes, limited RFID range, and battery life were observed but did not hinder its overall operation. With future enhancements like AI-based obstacle detection, adaptive gripping, and better power management, the system can become even more robust and efficient. In conclusion, LMR represents a significant step toward intelligent, user-centric library automation and has strong potential for real-world applications in modern library environments.

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