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DESIGN AND DEVELOPMENT OF SELF-EXPLAINING MOBILE ROBOT FOR LAB DEMONSTRATION

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Abstract: The utilization of robots is rapidly expanding across various industries, including manufacturing, hotels, hospitals, households, and education. These robots serve multiple purposes, such as assembly, material handling, and even has potential to provide guided tours to visitors in places like museums, colleges, and laboratories. This research paper focuses on the design and development of a self-explaining mobile robot specifically used for lab demonstrations. The primary objective of this project is to create a cost-effective and user-friendly robot capable of delivering informative lab tours to visitors. The robot incorporates infrared sensors to navigate its way throughout the lab, following a predetermined path. Additionally, the integration of a WIFI module enables the robot's remote activation and deactivation through an Android application. To enhance the visitors' experience, the robot is equipped with a dedicated sound system. This sound system provides detailed information about the lab's equipment, safety guidelines, and general lab procedures. The camera module plays a crucial role as it scans QR codes placed near specific equipment, triggering the sound system to deliver corresponding audio output. This project represents an innovative approach to introducing guests, students to the laboratory environment, creating a safe and informative experience that fosters their comfort and confidence within the lab setting.

Index Terms – Line follower, ESP32 camera, Arduino uno, ESP8266.

I. Introduction

Robotics in education is a rapidly expanding field that is revolutionizing the way we teach and learn. The incorporation of robots in education offers a dynamic and interactive approach, greatly enhancing student engagement. Over the past few years, robotics has gained significant popularity in education, particularly for teaching important STEM (science, technology, engineering, and math) concepts. Robotics can be employed in various educational settings, including classrooms and labs. Moreover, robots can be designed to serve as tour guides, assisting guests who arrive for college admissions or inquiries.

To fulfil the requirements of providing lab tours, the robot must have three key capabilities: navigation, sound system, and wireless control. Among various navigation technologies, the line follower method proves to be simple and cost-effective. In this approach, infrared sensors are utilized to trace a black line. Typically, two infrared sensors are employed one on the right and another on the left side of the robot. When the left sensor detects the black line, the robot turns left. This logic applies similarly to the right sensor, ensuring the robot consistently follows the black line. This line following concept is particularly useful when the path is predetermined. For wireless control, we have integrated a WIFI module into the robot's design. By utilizing the Blynk IoT application, the robot can be conveniently controlled using a smartphone, eliminating the need for complex Android application development. To provide information about the laboratory, we have implemented a specialized sound system. This system delivers audio output only when the corresponding QR code is scanned, ensuring relevant information is relayed to the guests seamlessly.

II. Literature Review

The use of robotics in healthcare, manufacturing, material handling, education has become increasingly popular in recent years, with many researchers exploring the potential of using robots to enhance learning and engagement in various fields, including science and engineering. The Arduino platform is a popular choice for robotics projects due to its low cost and open-source nature, making it accessible for students and educators.

In [1], an Arduino board, ultrasonic sensor, and smell sensor were used to create a smart moving dustbin. This project offers notable advantages in terms of cost-effectiveness and ease of development using Arduino. As technology continues to advance and smart cities emerge, there is a growing need for intelligent solid waste management solutions. The concept of a moving smart dustbin has been introduced to transform ordinary dustbins into smart ones by integrating sensor systems. Ultrasonic sensors detect obstacles, load sensors measure garbage weight, smell sensors identify unpleasant odors, and infrared sensors monitor the dustbin's fill level. These sensors enable the dustbin to move along a predefined path. The dustbin's status is displayed on a Liquid Crystal Display, providing user with real-time information. When the fill level reaches a certain threshold, the dustbin autonomously moves to the main garbage area along a predefined path with the assistance of a line follower robot. The waste is then emptied in the designated garbage area.

In [2], the rapid advancements in technology have facilitated the design and production of robots capable of performing tasks traditionally carried out by humans. By eliminating drawbacks associated with human activities such as boredom, fear, and inefficiency, robots offer significant advantages. This study focuses on the development of a mobile line-following robot equipped with sensors to detect high radiation levels in a sample farmland. The robot navigates across a grid, moving through squares measuring 60 cm x 60 cm, and coloured silver. Two infrared sensors, Arduino Uno, two DC motors, and an LDR sensor were utilized in this project. The robot successfully detects radioactive materials as it moves along the lines, and the findings are presented on a 7-segment display. The robot's objective is to explore the grid, identifying areas with high radiation levels and reporting the total number of squares and the number of high radiation areas discovered.

The paper [3] implemented the line follower concept to develop a room service robot suitable for hospital environments. The primary application of this robot is to efficiently perform room service tasks, with a particular focus on delivering drugs, small items, and food, which are commonly required services. The system's potential extends to similar environments characterized by repetitive tasks and static, stable conditions, such as delivering medication to patient beds in hospitals or serving food to individual tables in restaurants. The line follower robot is controlled by the ESP8266 microcontroller, chosen for its affordability, Wi-Fi capability, and ease of programming using the Arduino IDE software. Operating at 5 volts and consuming a current of 3 mA, the microcontroller drives the motion of the robot through four DC geared motors. These motors have an operating voltage range of 3V to 12V, a maximum torque of 800gf.cm, a load current ranging from 70mA to 250mA, and a speed of 148RPM. The L293D motor driver IC, utilizing two H-Bridges, is employed to regulate motor speed and control motion. The robot is also equipped with two infrared sensors and one ultrasonic sensor to avoid collisions and ensure safe navigation.

In [4], in response to the rapid spread of COVID-19 and the shortage of medical staff in hospitals, the author designed a line-following robot to control patient bed movement. With the goal of reducing contact between medical personnel and infected patients, the robot autonomously transfers patients from ambulances to their rooms. It operates based on an Arduino program and follows lines installed on the hospital floor, requiring no human intervention. This robot makes safe environment as there is no need for staff to get close to infected patient. The robot consists of an Arduino board, two infrared sensors, a battery, a Bluetooth module, and four DC motors. The author successfully tested a prototype of the robot within a hospital environment.

The research paper [5] demonstrates the development of a mobile surveillance camera monitoring system utilizing a line follower for easy mobility. The experiment also incorporates obstacle detection using a camera. The methodology is divided into three stages: line following robot using Arduino, development of the monitoring system using LabVIEW, and combining the first two stages into a line following monitoring system. The paper details the working principle, flowchart, and development process of the line following surveillance camera monitoring system. The prototype successfully follows the line path with minimal deviation, showcasing potential for an intelligent patrol robot applicable to residential areas.

In [6], the authors present the development of a line-following mobile robot employing an LM3S811 ARM Cortex-3-based microcontroller as the main controller. The robot utilizes eight IR sensors to track the path and incorporates a PID control algorithm to enhance navigation reliability. The robot is composed of five main parts: chassis and body, sensors and signal processing circuits, microcontroller, motor driver, and actuators. The chassis serves as the main structure to house all components, while infrared sensors detect the path and direction. The IC L298 acts as the motor driver, controlling two motors selected for their consistent speed regardless of inclines. A quadratic line detection algorithm, employing quadratic interpolation, is utilized for robot's programming. The dynamic PID algorithm-controlled robot outperforms the simple on-off robot, as evaluated in terms of performance and reliability.

The paper [7] details the design and implementation of a line-following robot capable of tracking a black line on a white surface. The robot operates in two distinct modes: line-following mode and obstacle detection mode. Similar to a robotic car, this system follows a predefined path while being capable of identifying obstacles to the right, left, and front of its trajectory. It possesses the ability to move along the black line while simultaneously detecting obstacles in all directions. The design process involves knowledge of Arduino programming, electrical circuit integration, and a basic understanding of electronics principles to develop the robot using Arduino Uno. The robot incorporates three sonars strategically placed for improved obstacle detection and two infrared sensors connected to a microcontroller. Powered by a 6-volt rechargeable lithium battery, the robot can carry up to 600g of components without deviating from its designated path. The research paper explains the block diagram, flowchart, circuit diagram, and Arduino coding of the line follower robot. The sensing mechanism for detecting the line and the utilization of three ultrasonic sensors for obstacle detection are described in detail. The project concludes by showcasing the successful operation of the line follower robot with obstacle avoidance, emphasizing its cost-effectiveness.

The paper [8] introduces a line-following robot utilizing Arduino technology to improve the transportation of essential materials in healthcare institutions and industries. The proposed system detects a black path and moves in its direction, streamlining material conveyance and reducing the need for human intervention. The technology aims to achieve secure, punctual, and efficient goods transportation. The paper focuses on optimizing the robot's controlled movement by tuning control parameters to enhance overall performance. The robot is primarily designed to follow a predetermined path, utilizing two sensors to locate and navigate along it. Such robots find applications in industrial plants with pick and place facilities, efficiently transporting components from source to destination on fixed paths. The paper is divided into hardware and software modules, specifying the materials used for the project, including Arduino UNO, L293D motor driver module, DC motors, robot chassis, IR sensor module, insulation tape, conductors, 9V battery, and battery cap. The research paper explains the operation of the line follower robot and presents a comparative study of its performance on uniform and non-uniform surfaces.

In [9], the authors present a photodiode sensor-based line follower robot designed to track a black line on a white surface. The electromechanical robot operates at a maximum RPM of 180 under frictionless conditions and is equipped to detect and correct its path if it deviates from the desired trajectory. The paper provides comprehensive explanations of concepts related to infrared sensors, ultrasonic sensors, and microcontrollers.

In [10], the authors develop a pill delivery system for patients in hospital environments, incorporating the line follower concept. The paper also discusses the advantages of such a system, highlighting how the integration of pill delivery and dispensing technologies can simplify medication management for individuals, healthcare professionals, and healthcare systems. These technologies offer cost savings, enable remote patient monitoring, enhance convenience, improve medication accuracy, and promote adherence. Additionally, by reducing the need for in-person visits to doctors' offices and pharmacies, the integration of these systems contributes to overall cost savings. Thus, the installation of pill delivery and dispensing systems significantly improves the medication management process, leading to better patient health outcomes and reduced costs for healthcare organizations.

Arduino is a widely-used microcontroller platform in robotics, popular among hobbyists and professionals alike. It has been used in a variety of robotics projects, including mobile robots, robotic arms, and drones. Its flexibility and ease of use make it an ideal platform for building educational robots. Studies suggest that robots can be effective teaching tools in the laboratory, providing students with real-time feedback and instruction.

III. Problem Statement

The main inspiration to make this robot is that we observe during the admission period in colleges that a lot of parents and students come to the college to see the facilities, such as classrooms, sports sections, laboratories, and practical equipment. Consequently, the process of giving tours of the college to parents and students occurs for each group of visitors, and the number of visitors arriving at the college is large. As a result, it becomes a repetitive process, and in the case of understaffed conditions, giving tours to multiple visitors can be difficult. This is why we propose using robots for such tasks. The aim of this project is to introduce a single laboratory to visitors using a robot.

IV. Objective

The primary objective of the robot is to autonomously navigate around the lab by following a black line, using an infrared sensor to detect the line and stop at the corresponding equipment. Additionally, a camera module scans QR codes located near the equipment, transmitting signals to the sound system that trigger the playback of the respective audio files. Once the information is provided, the robot proceeds to the next equipment, ensuring a comprehensive lab demonstration for the guests.

V. Methodology

The methodology for developing a robot is crucial as it lays the foundation for systematic and efficient progress. It ensures the identification of specific objectives, the selection of appropriate tools and technologies, and the establishment of clear evaluation metrics. A well-defined methodology fosters innovation, streamlines development, and enhances the overall success of creating a functional and reliable robot. Development of this robot is going to be difficult due to electronics complexity and its interaction with surrounding lab environment during demonstration that is why it become important to create a good methodology so we could achieve desired results. The provided methodology helps in identifying specific objectives, selecting appropriate components and technologies such as IoT devices and cameras, conducting extensive testing for performance evaluation, and integrating various features like remote operation and QR code interaction. It ensures the robot's successful integration of components like the Arduino Uno board, making it cost-effective and easier to develop, while achieving a valuable addition to educational environments and showcasing its potential applications in various fields.

The steps to develop a robot are as follow:

1. Robot's Path Design: The initial phase involves designing the optimal path for the robot to navigate within the laboratory.
2. Robot's Body Design: The first step in constructing the robot entails designing its physical structure and layout.
3. Hardware Selection: This stage involves carefully selecting suitable sensors, speakers, and other components required for the robot's functionality.
4. Assembly: The components are assembled, creating a temporary setup for testing. This includes mounting the sensors, speaker, and other components onto the robot's chassis and set up connections with the Arduino board.
5. Programming: The robot's movements and sensor data processing are programmed using the Arduino IDE and C++ language. This involves developing code to control the robot's motion and interpret sensor readings.
6. Audio Generation: A script is written to introduce the lab, which is then converted into audio format using murf.ai or a similar platform capable of transforming text into audio.
7. Testing: The robot undergoes thorough testing to ensure its proper functionality. This includes evaluating its movement capabilities, sensor accuracy, and the quality of audio output.

8. Refinement: Based on the results obtained from testing, necessary adjustments are made to enhance the robot's design, programming, or components.
9. Deployment: In the final stage, the robot is deployed within the laboratory, where it serves the purpose of introducing new students and guests to the lab environment.

VI. Laboratory Layout and Robot's Pathway

The figure below shows path of robot and lab layout.

1. The actual path of the robot is indicated by a red dotted line.
2. The first setup is denoted by grey-colored boxes.
3. The second setup is marked by yellow-colored boxes.
4. The initial position of the robot, represented by an orange dot, is position 1. At this position, the robot provides general information about the lab before proceeding towards position 2.
5. The robot's second position is at position 2, where it stops and delivers information specifically about the setup and moves towards position 3.
6. Similarly, the robot stops at position 3 to provide information about the setup before returning to its initial position.

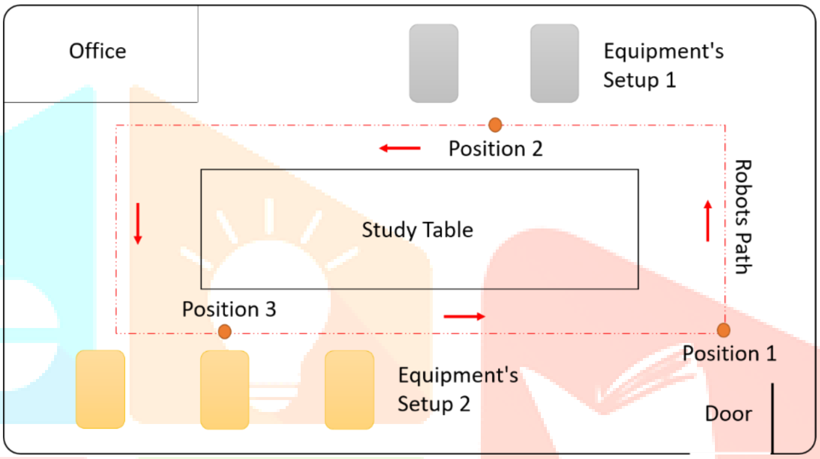

Fig.1 Layout of laboratory and path of robot

VII. 3D Modelling and Dimensions of Robot

To facilitate 3D modeling, we used the AUTO CAD software. The robot's dimensions are as follows: a width and length of 25 cm and a height of 40 cm. The wheels used has a diameter of 9 cm and a width of 1.8 cm. The upper body of the robot features a conical frustum shape, with a circle at the base measuring 24 cm in diameter and a taper angle of 7 degrees for the frustum shape. The height of the upper body is 27.5 cm.

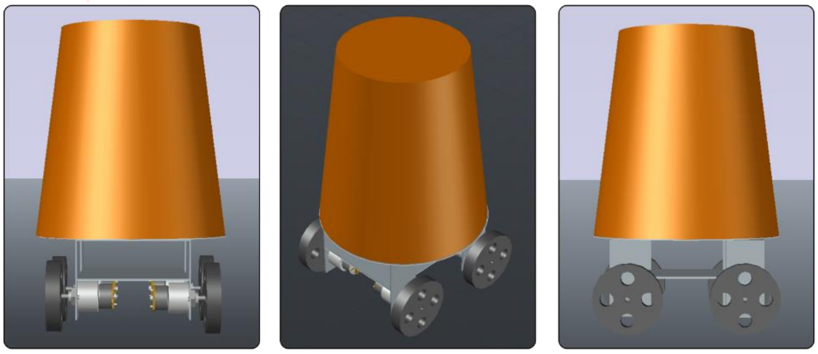

Fig.2 Three-dimensional model of robot

VIII. Robot's Working and Electronic System

In this robot, two infrared sensors are utilized for line following purposes. One sensor is positioned on the right-hand side of the robot, while the other is placed on the left-hand side. The desired path is marked by a black line drawn on the floor, and the robot is positioned in such a way that the black line falls between the two infrared sensors. When both sensors fail to detect the black line, the robot continues moving forward. If the left infrared sensor detects the black line, the robot turns left, and if the right infrared sensor detects the line, the robot turns right, thereby maintaining its intended path.

To control the robot's motion along the path, we have implemented a combination of the ESP8266MOD Wi-Fi module, a single-channel relay, and the Blynk IoT Android application. The robot's power is initially turned on, and the Wi-Fi module establishes a connection with the Blynk IoT application. Within the application, an on-off switch is created to control the power supply to the motor driver. By activating the robot through the application, the Wi-Fi module energizes the motor driver via the single-channel relay. Conversely, switching off the robot deactivates the power supply to the motor driver through the relay. This method allows us to start and stop the robot conveniently. For audio output, a dedicated sound system is incorporated into the robot. This sound system is triggered when the robot's ESP32 camera scans QR codes positioned near specific equipment in the lab. Three QR codes are placed in proximity to their corresponding equipment, and when scanned by the robot, the sound system plays the audio assigned to that respective QR code. Once the robot completes its traversal of all positions within the lab, it returns to its initial starting position. The complete circuit diagram is illustrated in the accompanying figure.

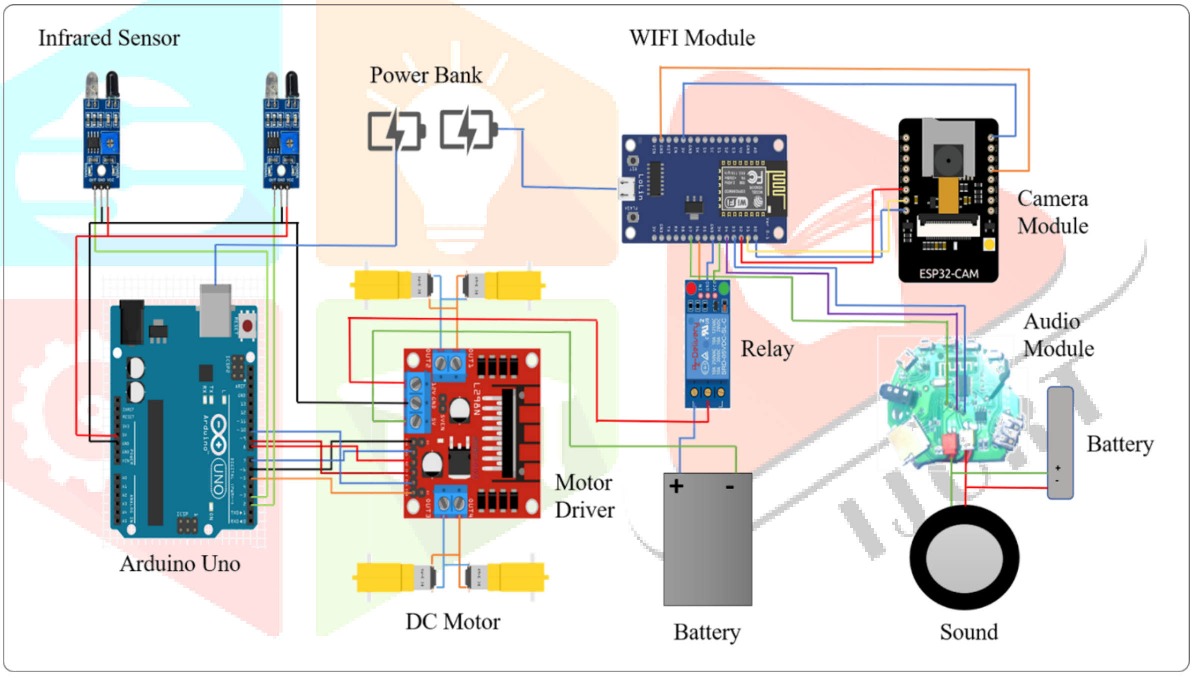

Fig.3 Circuit diagram

IX. Testing and Validation of Robot

The robot demonstrated precise line following capabilities through the effective utilization of the two infrared sensors. The integration of the WIFI module ESP8266MOD, single-channel relay, and Blynk IoT Android application offered a seamless and user-friendly approach to initiating and halting the robot's movement along the designated path. The incorporation of a dedicated sound system further enhanced the robot's functionality, enabling it to deliver specific audio outputs based on the QR codes scanned by its ESP32 camera. Moreover, upon successfully traversing all positions within the lab, the robot autonomously returns to its initial starting point and successfully completing its assigned task.

Fig.4 Testing and validation of robot in laboratory

X. Applications of Robot

1. Education: The robot can be used for teaching or laboratory, school, college introduction.
2. Museums: The robot can be used in museums to give tour to visitors.
3. Laboratories: The robot can be used in laboratories to move small objects, such as test tubes, from one location to another. It can also be used to collect data from sensors or perform other tasks.
4. Hospitals: The robot can be used in hospitals to transport small items, such as medication or medical equipment, from one location to another. This can help reduce the workload of hospital staff and increase efficiency [10].

XI. Conclusion

The research paper introduced an innovative approach to utilizing robotics for lab demonstration purposes in educational institutions. It highlighted the widespread application of the line follower concept across various fields, including hospitals, hotels, and material handling, for navigation purposes. Within the paper, extensive testing was conducted to evaluate the robot's performance, specifically its ability to accurately follow a predefined path represented by a black line. A key highlight of the research is the successful integration of an IoT (Internet of Things) device, which facilitated seamless control of the robot. This IoT integration not only enhanced the robot's functionality but also opened possibilities for remote operation and monitoring, making it a valuable addition to the educational environment. Another noteworthy achievement discussed in the paper is the incorporation of an ESP32 camera, which enabled the robot to scan QR codes for efficient interaction with the environment. The acquisition of audio output based on the scanned QR codes showcased the robot's ability to interact with its surroundings intelligently, providing an enriched user experience. The utilization of the Arduino Uno board significantly contributed to the robot's cost-effectiveness and ease of development.

XII. Future Scope

1. Improved Navigation: The robot's navigation can be improved by adding more sensors and using advanced algorithms to improve obstacle avoidance and path following. For example, the addition of a camera sensor could enable the robot to detect and avoid more complex obstacles, use of Lidar sensor, laser sensor for navigation [9].
2. Enhanced Functionality: The robot's functionality can be enhanced by adding additional features such as voice recognition, object detection, and remote-control capabilities. This could enable the robot to perform more complex tasks and be used in a wider range of applications.
3. Modular Design: The robot's design can be made more modular, allowing for easy expansion and customization. This could enable users to add new components and sensors to the robot, further enhancing its functionality.

Overall, the future scope for the Arduino-based lab demonstration robot is vast and can be designed to suit a wide range of needs and interests.

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