Lab Assistant Robot

A Minor Project-I Report

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CERTIFICATE

This is to certify that the report submitted along with the project entitled **“Lab Assistant Robot”** has been carried out by Devani Ayush (22BT04025), Rudradatt Purohit (22BT04122), Vraj Patel (22BT04155), Soham Kava (23BT04D179) were under my guidance in partial fulfilment for the degree of Bachelor of Technology in Computer Science and Engineering – 6^{th} Semester of GSFC University, Vadodara during the academic year 2024-25. The students have successfully completed the project activity under my guidance.

SIGNATURE (FACULTY MENTOR)

May, 2025

ACKNOWLEDGMENT

I would like to take this opportunity to express my deepest gratitude and appreciation to all those who have contributed to the successful completion of this project. First and foremost, I am immensely grateful to **Ms. Swati Saxena (Assistant Professor, CSE)** for her constant guidance, insightful suggestions and unwavering support throughout the development of this project. Her mentorship played a vital role in shaping the direction of our work and enhancing our understanding of both theoretical and practical aspects of the system. Finally, I would like to thank my teammates and peers for their collaboration and consistent efforts, which made this project a valuable and enriching learning experience. This project has truly helped us grow both technically and professionally and we are grateful for the opportunity to execute it.

ABSTRACT

Imagine walking into a lab where a smart robot guides you through each student project—no human assistance required. The Lab Assistant Robot is an interactive solution designed to enhance how visitors explore educational or demonstration spaces like laboratories, exhibitions, and tech fairs. Controlled through a mobile application, the robot moves manually between designated stations. Each station features a unique QR code, which the robot scans using an onboard camera.

Once scanned, the robot fetches the project details from a backend database. These details are then presented on a display connected to the robot and simultaneously narrated via a Bluetooth speaker using a text-to-speech system. This approach offers a dual-mode output—visual and audio—making the experience accessible and engaging.

The system emphasizes user autonomy, allowing visitors to explore at their own pace, skip projects, or revisit them. Unlike traditional autonomous navigation robots, this model simplifies operation by avoiding the complexities of sensor-based pathfinding, making it more cost-effective and easier to replicate. While initially aimed at academic institutions, the system is versatile enough to be deployed in museums, public exhibitions, or awareness campaigns where structured, interactive guidance is needed.

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1. INTRODUCTION

In educational institutions, particularly within engineering and technical departments, laboratories often showcase a variety of student-led projects. During events such as exhibitions, workshops and university open days, managing visitor interactions and effectively presenting each project becomes a logistical challenge. To address this, the **Lab Assistant Robot** has been developed as a self-guided, interactive solution that replaces the need for human presenters.

Controlled via a **mobile application**, the robot allows visitors to manually navigate through the lab. At each project station, a **QR code** is displayed. The robot uses an onboard **camera** to scan these QR codes, which are linked to a centralized database containing detailed project information. Once scanned, the robot displays the information on a screen and simultaneously plays an audio explanation through a **Bluetooth speaker**, enhancing both engagement and accessibility.

The system is intentionally designed to be cost-effective and straightforward, eliminating the need for complex autonomous navigation or obstacle detection. By giving visitors full manual control, the robot ensures a flexible and user-paced exploration experience, allowing them to skip or revisit projects as desired.

I. PROJECT DESCRIPTION

- **Problem Statement:**

Visitors in laboratories face difficulty accessing detailed information about items. To address this, there is a need for a wheeled robot that can scan QR codes, provide information interactively, and assist visitors in understanding laboratory items effectively.

- **Objectives:**

- **Mobile App-Based Navigation –** Enable users to manually control the robot's movement between project station using mobile application.
- **QR Code Scanning** – Use a camera to scan QR codes placed at each station and retrieve corresponding project information from a database.
- **Audio-Based Information Delivery** – Present project details through a speaker system for an engaging and accessible experience.

- **Flexible Project Access** – Allow users to skip or proceed to the next project through commands sent via the mobile app.
- **Improving Visitor Experience** – Provide a self-guided and user-friendly way for visitors to explore lab projects without the need for a human assistant.

II. FEATURES

- **App-Based Manual Navigation**: Users control the robot's direction and movement via a mobile app, ensuring simple and direct handling.
- **QR Code Scanning**: The robot scans QR codes located at each station to determine which project to present.
- **Display Output**: Project titles, summaries, or visuals are shown on a non-touch display mounted on the robot.
- **Audio Output**: Project descriptions are audibly delivered through a speaker, supporting both visual and auditory understanding.
- **Project Skipping Option**: Users can command the robot via the app to skip the current project or move to the next.

III. TOOLS AND TECHNOLOGIES USED

- **Microcontroller Unit (MCU)**: ESP32-WROOM, for motor controlling.
- **Single Board Computer(SBCs)**: Raspberry Pi 5, offering processing, Wi-Fi, and camera interfacing.
- **Web Camera**: Used to scan QR codes and capture the encoded data.
- **Display Module**: TFT LCD or similar display for visual output.
- **Speaker**: Provides audio playback for project descriptions.
- **Mobile App**: To connect with the robot via Wi-Fi or Bluetooth.
- **Database**: Firebase (for cloud) or local JSON/EEPROM storage to retrieve project information.
- **Programming Languages**: C (for ESP32 firmware **in ARDUINO IDE**), Python (for QR process), JSON (for database content).
-

IV. MAJOR COMPONENTS USED

- **Hardware Technologies**

  a. **Raspberry Pi 5 (8GB):** Central processing unit for QR scanning and UI.
  b. **ESP32:** For Motor Controlling.
  c. **10.1-inch Wave share Touchscreen:** User-friendly interface for navigation and for displaying project information.
  d. **Webcam:** Captures QR code and scan to load a project.
  e. Motors (x4) **Pro-Range OG555 High Torque DC Motor 12V 100RPM** 173.6N-cm.
  f. **BTS7960 Motor Driver Module:** Controls speed and direction of DC motors.
  g. Zen (12 V 12Ah) SMF **Rechargeable Battery.**
  h. **Mecanum Wheels** 100mm Diameter with 6mm Shaft.
  i. **DC-DC Step-Down Converter Module (Buck Converter):** Converts 12V power to 5V for ESP32 and Raspberry Pi.

j. **Speakers (Bluetooth):** Plays audio explanation.
k. **Jumper Wires & Switches:** For Connection with ESP32 and Raspberry Pi.

- **Software Technologies**

a. **Raspberry Pi OS** (Ubuntu - based): Runs the robot's function QR code scanning process and Fetch data from backhand.
b. **Python:** Handles QR scanning and GUI development.
c. **OpenCV:** Enables QR code detection and object recognition.
d. **Text-to-Speech** (espeaK): Converts text descriptions into voice output.
e. **MySQL Database:** Stores project information.
f. **Arduino IDE:** For ESP32 development board configuration.
g. **Tinker:** For UI development
h. **SQLite:** Storing Information in Database
i. **Pyzabar:** For Image Processing

2. LITERATURE REVIEW

2.1 REVIEW:

A_comparative_study_on_LIDAR_and_Ultrasonic_Sensor_for_Obstacle_Avoidance_ Robot_Car

2.1.1 Summary: The field of assistive robotics in educational and laboratory environments has seen significant innovation. One study, *"A Comparative Study on LIDAR and Ultrasonic Sensor for Obstacle Avoidance Robot Car"*, examines two popular obstacle detection technologies. It concludes that while LIDAR provides superior accuracy and range, ultrasonic sensors are more affordable and easier to implement, though less precise in complex environments.

2.1.2 Tools & Technologies:

- LIDAR sensors.
- Ultrasonic sensors.
- Microcontrollers (e.g., Arduino).
- Motor drivers.

2.1.3 Advantages:

- LIDAR offers high-resolution mapping and precise distance measurement.
- Ultrasonic sensors are cost-effective and simple to implement.

2.1.4 Drawbacks:

- LIDAR systems can be expensive and may struggle with reflective surfaces.
- Ultrasonic sensors have limited range and lower accuracy.

2.2 REVIEW:

Learn Buddy Path Following Lab Assistant Robot

2.2.1 Summary: The second work, *"Learn Buddy: Path Following Lab Assistant Robot"*, introduces a robot that aids students by following a fixed path across the lab, displaying project information and playing audio instructions. While effective in delivering structured guidance, the system lacks adaptability and autonomous decision-making, relying heavily on predefined navigation.

2.2.2 Tools & Technologies:

- Line-following sensors.
- Microcontrollers.
- Display units for information dissemination.
- Audio modules for verbal assistance.

2.2.3 Advantages:

- Enhances interactive learning experiences.
- Automates information delivery in labs.

2.2.4 Drawbacks:

- Limited adaptability to dynamic environments.
- Relies on predefined paths, reducing flexibility.

2.3 REVIEW:

Socially Assistive Robot as Laboratory Safety Assistant for ScienceStudens

2.3.1 Summary: Lastly, the study *"Socially Assistive Robot as Laboratory Safety Assistant for Science Students"* showcases a robot used for monitoring student activity to ensure safety. It integrates behavioural detection and voice feedback, promoting responsible lab conduct. However, the robot's complexity and potential privacy concerns present notable limitations.

2.3.2 Tools & Technologies:

- Advanced sensors for behaviour detection.
- Interactive dashboards.
- User-centered design approaches.

2.3.3 Advantages:

- Improves safety by proactively identifying risky behaviours.
- Provides immediate feedback, reducing the likelihood of accidents.

2.3.4 Drawbacks:

- Implementation complexity due to advanced sensor integration.
- Potential privacy concerns with behaviour monitoring.

3. SYSTEM DESIGN

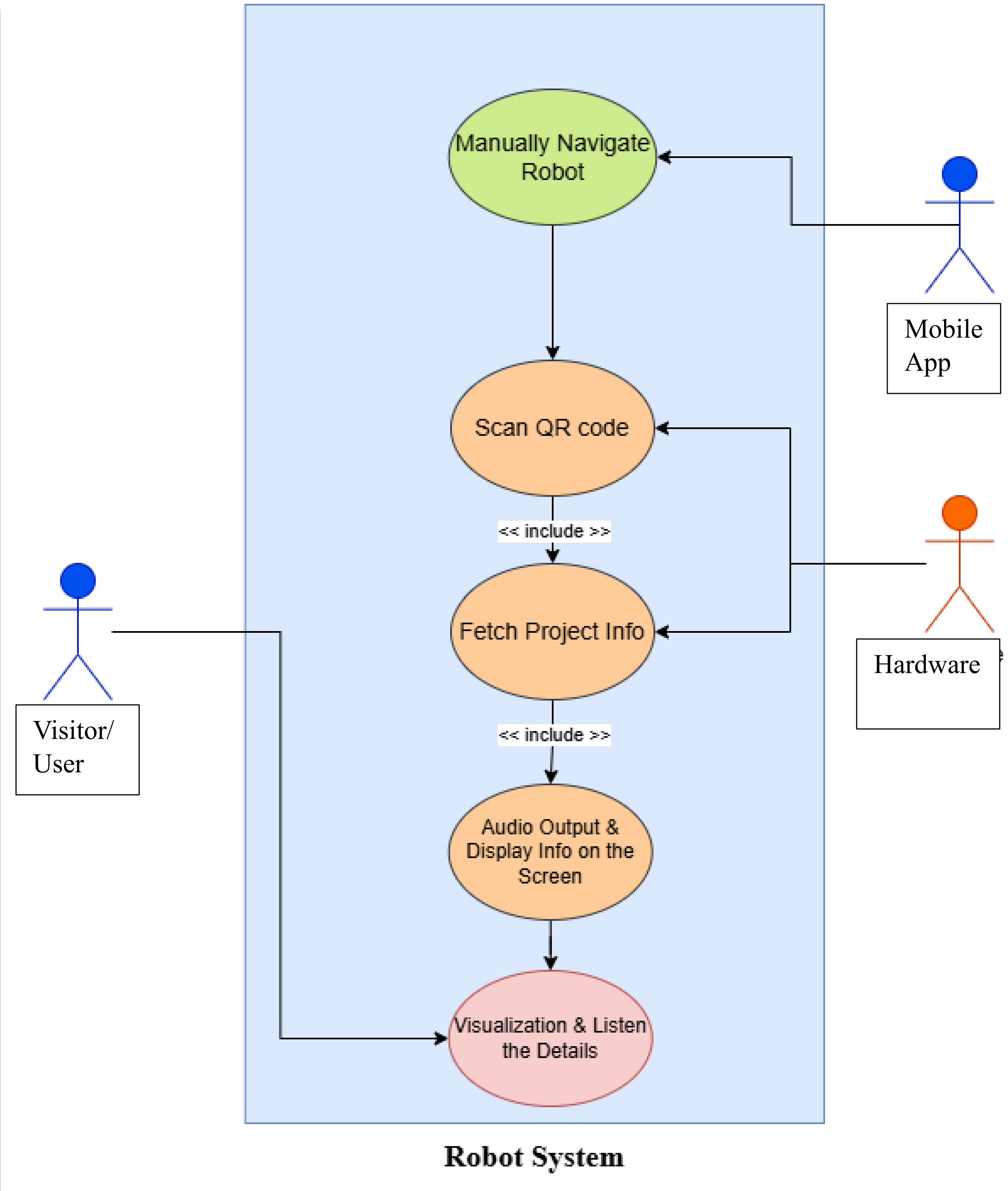


Fig. (1) UseCase Diagram of a System

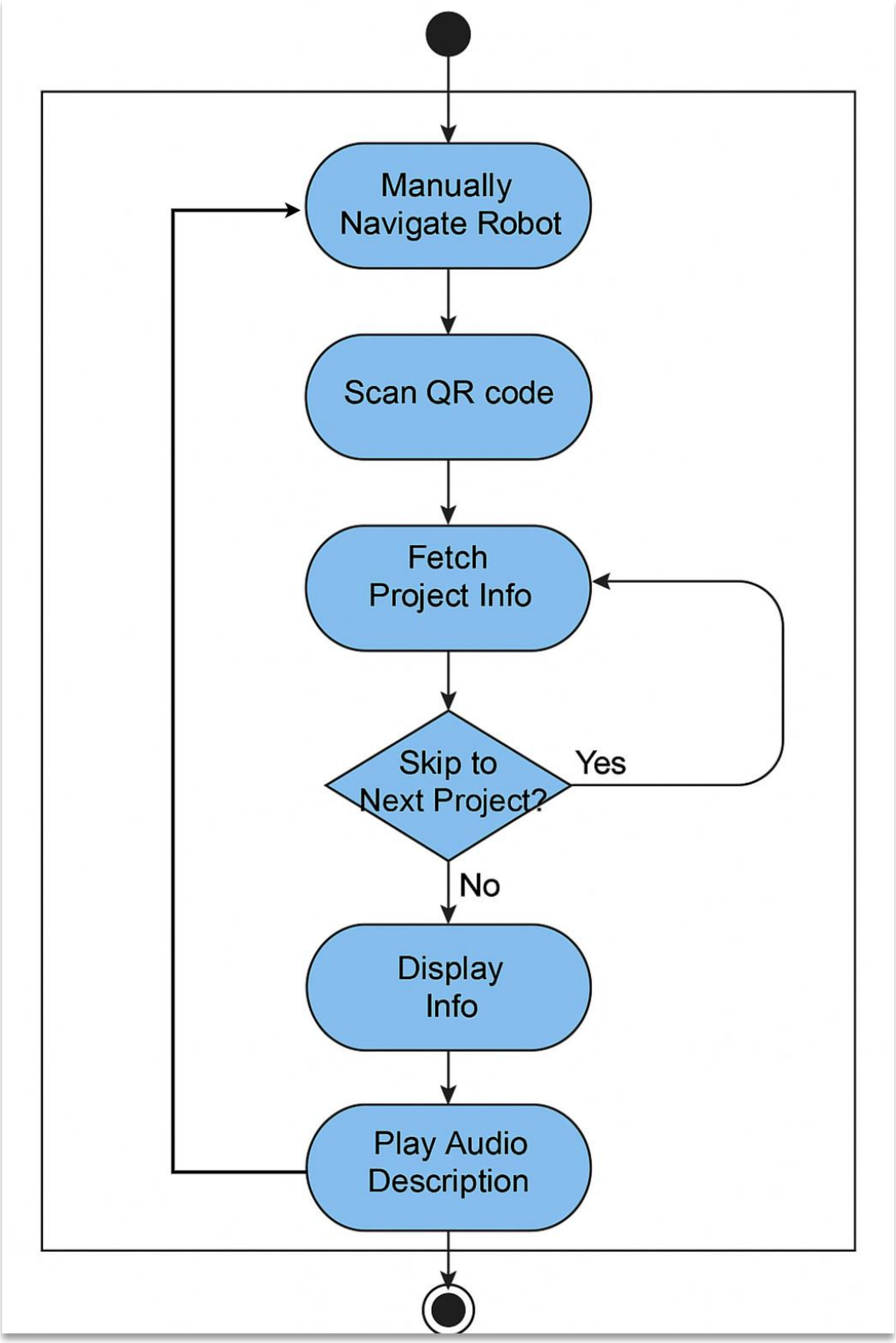


Fig. (2) Activity Diagram of a System

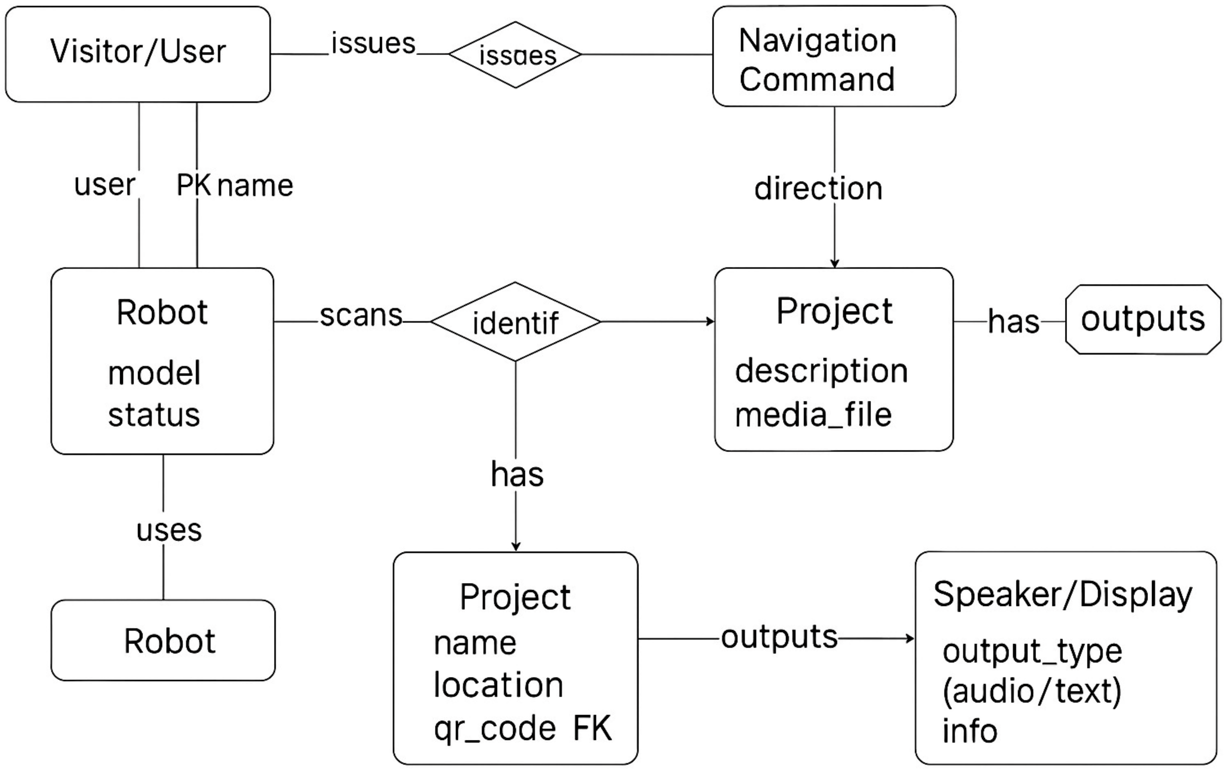


Fig. (3) Entity-Relationship (E-R) Diagram of a System

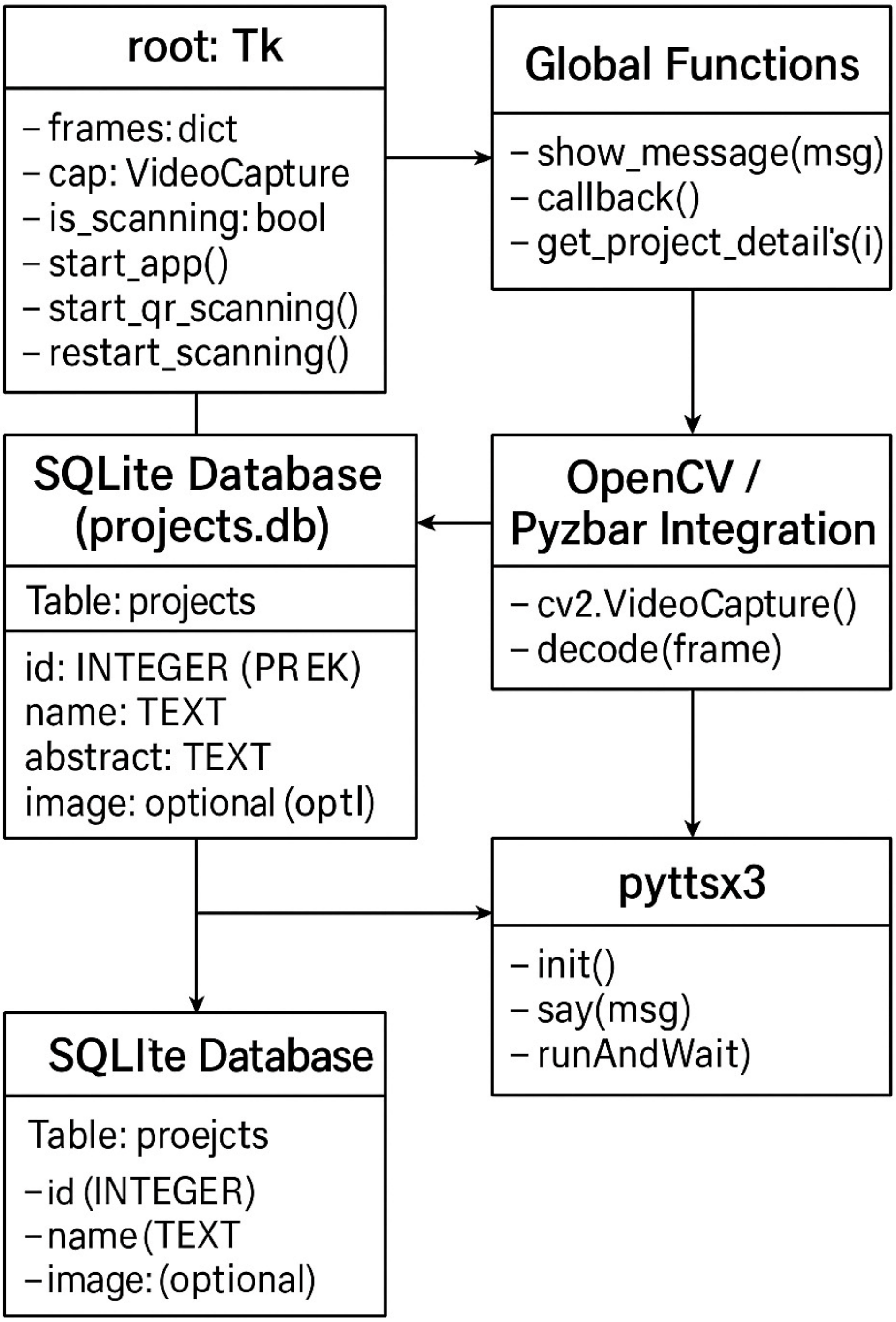


Fig. (4) Class Diagram of a Syste

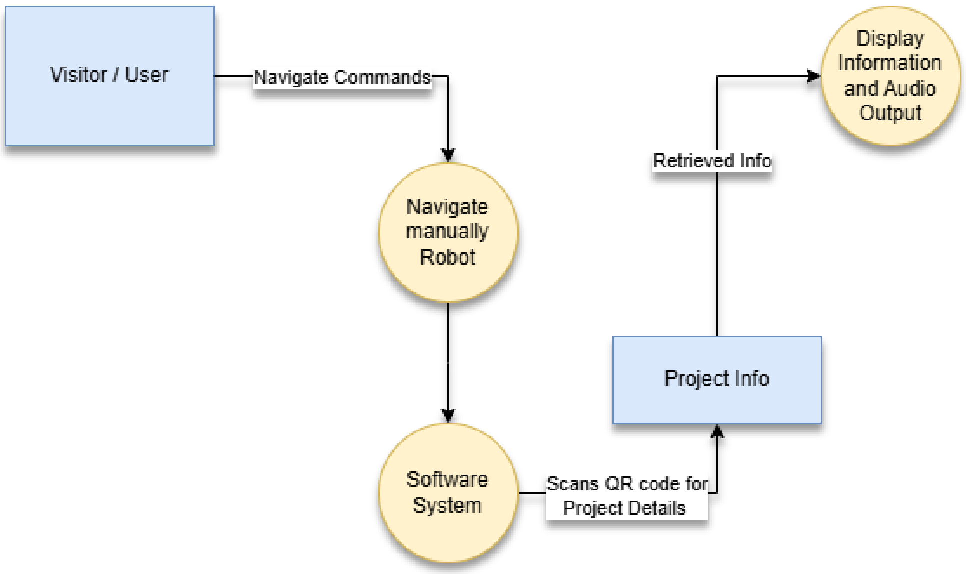


Fig. (5) Data Flow Diagram of a System

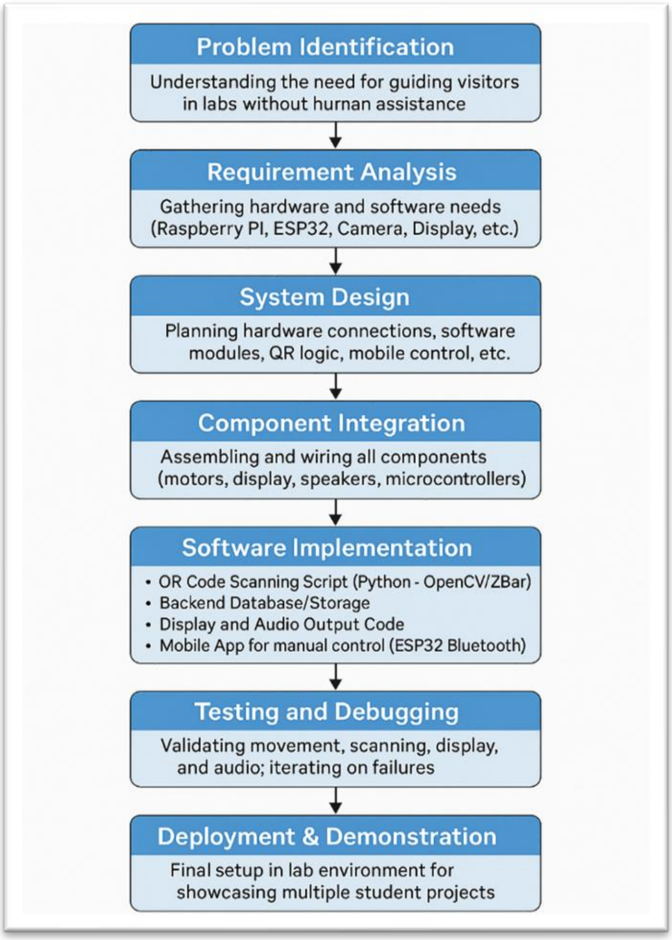


Fig. (6) Project Developmnet approach

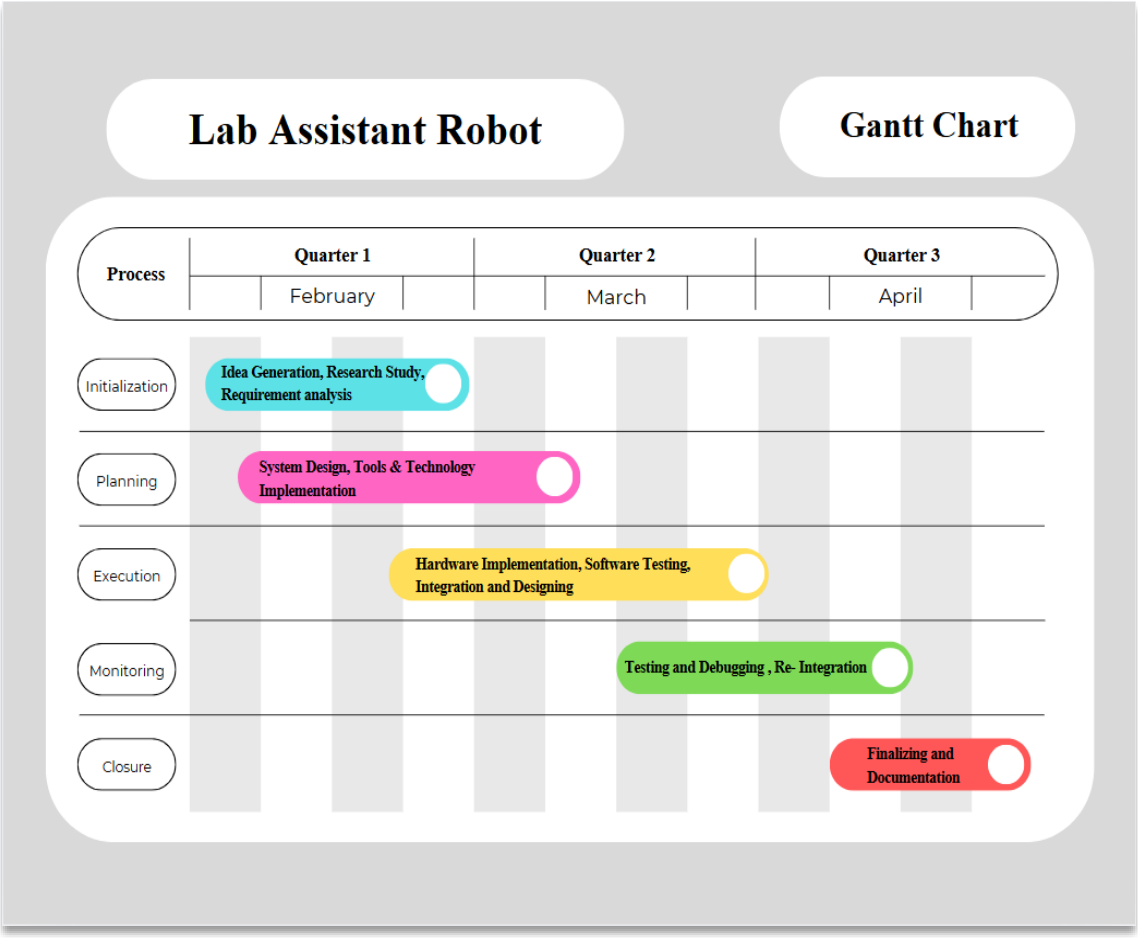
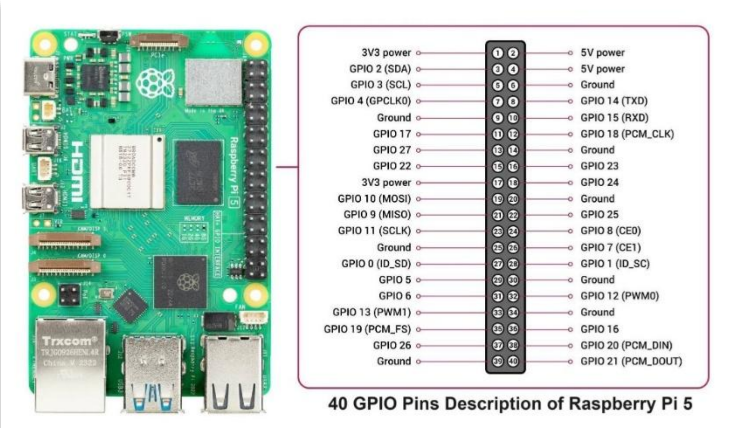


Fig. (7) Flow chart of a Development Process (Gantt Chart)

4. COMPONENTS DESCRIPTION

I. Raspberry Pi 5

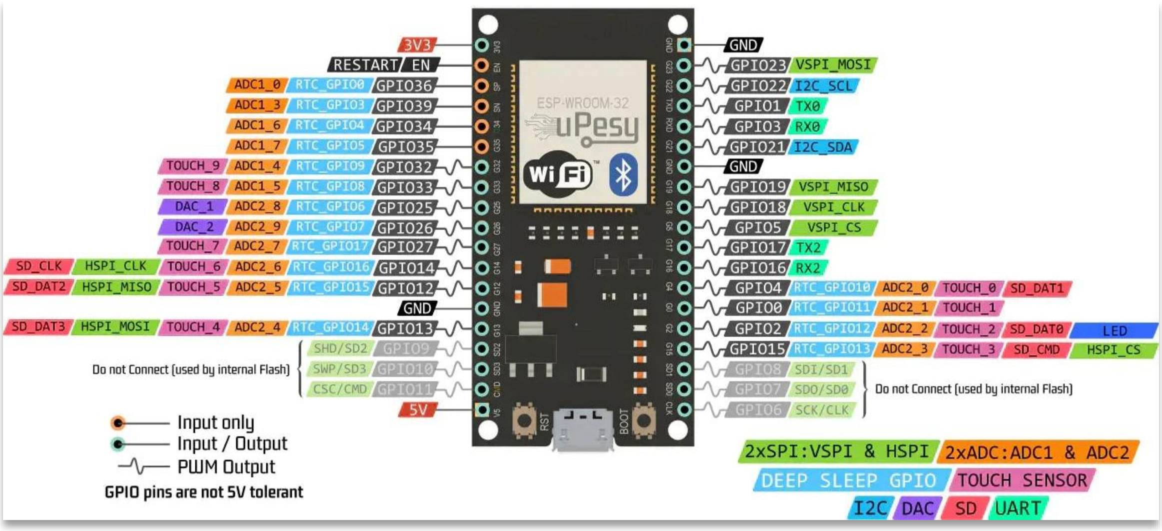
The Raspberry Pi 5 is a powerful single-board computer used as the brain of the robot. It handles image processing for QR code scanning, manages data flow, and controls peripheral devices. Its high processing speed and GPIO support make it ideal for multi-sensor and multimedia applications.



40 GPIO Pins Description of Raspberry Pi 5

II. ESP32-WROOM Module

The ESP32-WROOM is a dual-core microcontroller with built-in Wi-Fi and Bluetooth capabilities. In this project, it's responsible for communication with the mobile app, motor control via the BTS7960 driver, and real-time execution of navigation commands. It offers low-power operation and high-speed wireless connectivity.

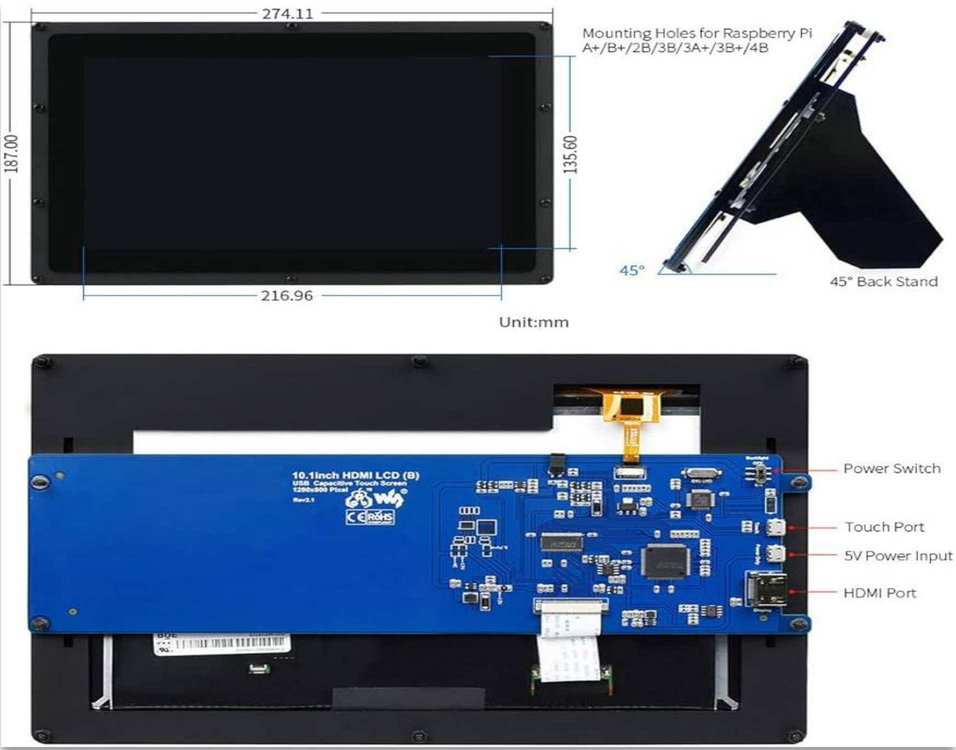


III. E900 Meet Webcam

The E900 Meet webcam serves as the visual input device for scanning QR codes at project stations. It captures clear images even under variable lighting conditions and sends them to the Raspberry Pi for decoding. Its plug-and-play nature ensures easy USB integration with the Raspberry Pi.

IV. Wave share 10.1 Inch Display

This HDMI-compatible display provides a high-resolution visual output of project information retrieved from the database. It acts as an interface between the robot and the user, making information accessible and engaging. The touchscreen variant can further enhance interactivity, if implemented.

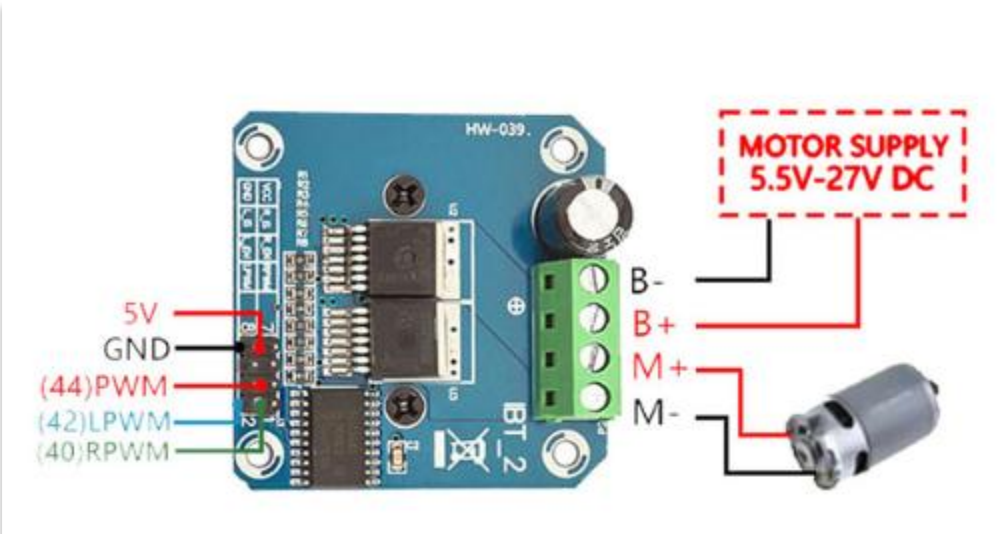


V. OG555 High Torque DC Motor (12V, 100RPM, 173.6 N-cm)

These motors are responsible for the physical movement of the robot. With high torque output, they provide enough power to drive the robot on different surfaces while maintaining smooth and controlled navigation. The 100 RPM speed offers a balance between speed and stability.

VI. BTS7960 Motor Driver Module

This dual H-Bridge motor driver can handle high current (up to 43A), making it suitable for controlling heavy-duty DC motors. It receives PWM signals from the ESP32 to regulate motor speed and direction. Its robust design ensures safe and efficient motor control.

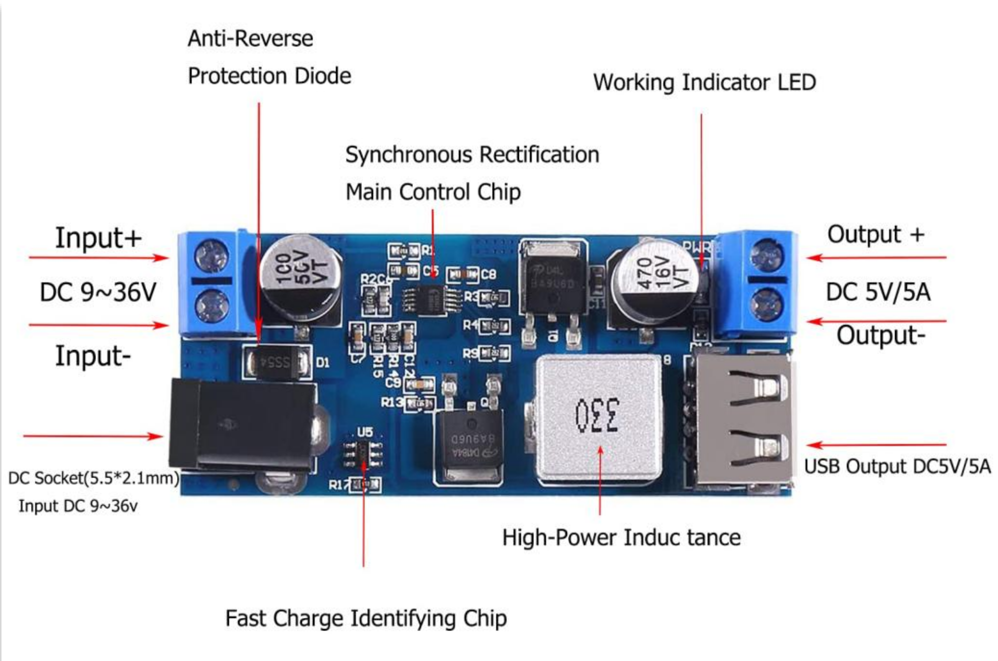


VII. 12V 12Ah Rechargeable Battery

The battery supplies power to the entire robot system, including motors, ESP32, and the display. With a high capacity of 12Ah, it ensures long operational time without frequent recharging, making it ideal for continuous event use.

VIII. USB Pin Buck Converter (12V to 5V)

This step-down converter regulates the 12V battery supply down to 5V, which is required to safely power devices like the Raspberry Pi and webcam. It ensures consistent and stable voltage, preventing damage to sensitive electronics.



IX. Bluetooth Speaker

The speaker delivers clear audio output, providing spoken project descriptions to enhance visitor engagement. It connects wirelessly to the Raspberry Pi and helps in making the system accessible to visually impaired users or enhancing public communication.

X. Jumper and Connecting Wires

Jumper wires are essential for connecting all electronic components on the breadboard or PCB. They ensure proper signal and power transmission between modules. These provide flexibility and modularity during both prototyping and implementation stages.

XI. Raspberry Pi OS:

Raspberry Pi OS is a Debian-based operating system optimized for Raspberry Pi hardware. In this project, it manages the main operations such as camera handling, QR code scanning, GUI display, and communication with hardware. It ensures efficient multitasking in a lightweight environment.

XII. Python:

Python is the core programming language used to develop the robot's logic. It handles QR code scanning, database access, GUI updates, and text-to-speech output. Its simplicity and vast library support make it ideal for this integrated system.

XIII. OpenCV:

OpenCV is used for real-time computer vision tasks like QR code detection. Integrated with Python, it enables the robot to process camera input efficiently and decode QR data for further processing.

XIV. eSpeak (Text-to-Speech):

eSpeak converts project information into speech, allowing the robot to narrate details after a QR scan. It supports multiple languages and works efficiently on limited hardware like Raspberry Pi.

XV. Arduino IDE (ESP32 Programming):

The Arduino IDE is used to program the ESP32 microcontroller, which handles motor movement and navigation. It communicates with Raspberry Pi to execute manual navigation commands.

XVI. Tinker (UI Development):

Tinker creates a GUI on the robot's display to show project information. It offers buttons, text areas, and labels for an interactive user interface linked to QR code inputs.

XVII. SQLite:

SQLite provides local, lightweight data storage for quick access to project information. It ensures offline functionality and fast response when networked MySQL isn't available.

XIX. PyZbar:

PyZbar is a Python library used to decode QR codes from images or video streams. It works alongside OpenCV to trigger project-specific actions like data retrieval and display.

5. IMPLEMENTATION OF PROJECT

(Methodologies & Approach)

5.1 Overview

The implementation phase focuses on the actual realization of the Lab Assistant Robot, based on the planned design and requirements. This chapter covers the methodological approach, system development process, hardware integration, software architecture, and communication flow between modules. The aim is to build a cost-effective, user-controlled robot that enhances project interaction during academic exhibitions.

5.2 Project Methodology

The **Incremental Development Model** was adopted for this project. This approach allowed us to divide the system into manageable modules such as movement control, QR code scanning, display output, and audio narration. Each module was developed and tested individually before being integrated into the final system.

Steps Followed:

i. **Requirement Gathering & Planning**
   - Define system objectives.
   - Identify key hardware/software components.

ii. **System Design**
   - Design circuit schematics and communication logic.
   - Create flowcharts, ER diagrams, and DFDs.
   -

iii. **Module Implementation**
   - Develop and test each component: motor driver, camera, display, etc.

iv. **Integration & Testing**
   - Combine all modules and conduct unit testing and system-level testing.

v. **Deployment**
   - Assemble the robot, upload firmware, and install the final setup in a real lab environment.

5.3 Hardware Integration Approach

- **ESP32-WROOM** is used as the controller for motor control and mobile communication via Bluetooth.
- **Raspberry Pi 5** serves as the central processor for QR code scanning, data retrieval, and media output.
- **Motor Driver (BTS7960)** connected to the ESP32 drives two high-torque DC motors.
- **Webcam (E900 Meet)** is connected to the Raspberry Pi to scan QR codes placed at project stations.
- **Wave share 10.1” Display** and **Bluetooth Speaker** are also connected to Raspberry Pi for visual and audio output.
- **12V 12Ah Battery** powers motors and ESP32, while a **buck converter** steps down voltage for Raspberry Pi and peripherals.

5.4 Software Implementation

- **Python & OpenCV** used for QR code scanning and data handling on Raspberry Pi.
- **C/C++ with ESP-IDF** or Arduino framework used to program ESP32 for motor control and Bluetooth communication.
- A **simple mobile app** (built using MIT App Inventor or Android Studio) sends directional commands to ESP32 over Bluetooth.

- Retrieved data is stored in a **local SQLite database** or text files for quick access upon QR code detection.
- **VLC library** used to play audio explanations of projects.

5.5 Data Flow and Communication

- When a user navigates the robot to a station via the mobile app, the webcam scans the QR code.
- Raspberry Pi decodes the QR and fetches relevant project information.
- The data is simultaneously shown on the Wave share display and narrated through the speaker.
- After one project is completed, users can navigate to the next project using the app.

4.6 Advantages of the Methodology

- **Modular Design:** Easier testing and debugging.
- **Incremental Development:** Smooth integration and gradual enhancement.
- **User-Driven Navigation:** Eliminates the need for autonomous navigation and obstacle sensors.

6. MODEL OVERVIEW

The Lab Assistant Robot is a semi-autonomous, user-controlled robotic system designed to guide visitors through student projects in a laboratory setting. The robot follows a **modular architecture**, integrating mechanical, electronic, and software components that work together to deliver a seamless interactive experience.

6.1 KEY FUNTIONAL COMPONENTS:-

6.1.1 Navigation Module

- Controlled via a **mobile application** using **Bluetooth** communication with the **ESP32-WROOM** module.
- Drives **high-torque DC motors** using the **BTS7960 motor driver**, allowing manual forward, backward, left, and right motion.

6.1.2 QR Code Recognition Module

- A **Meet E900 webcam** mounted on the robot captures and scans QR codes placed near each student project.
- Connected to a **Raspberry Pi 5**, which processes the scanned QR code using **OpenCV** and extracts project-specific identifiers.

6.1.3 Information Display & Audio Output Module

- After retrieving data linked to a QR code, the Raspberry Pi displays the project description on a **10.1-inch Wave share display**.
  Simultaneously, the robot plays a pre-recorded audio description via a **Bluetooth speaker**, enhancing accessibility.

6.1.4 Power Management System

- Powered by a **12V 12Ah rechargeable battery**.
- A **buck converter** steps down voltage for Raspberry Pi (5V) and other components safely.

6.2 SYSTEM WORKFLOW

- The user navigates the robot via the app → The robot reaches a station → The camera scans the QR code → Raspberry Pi fetches and displays project info → Audio narration is played → User moves to the next station.

7. CHALLENGES & FUTURE ENHANCEMENTS

7.1CHALLENGES

7.1.1 Hardware Integration Complexity

Coordinating multiple components like the Raspberry Pi (with webcam, speaker, and display) and the ESP32 (with motor drivers) involved complex wiring, voltage level matching, and effective space management on the robot.

7.1.2 Power Management

Providing stable 12V to high-torque motors while protecting sensitive components like the Raspberry Pi and ESP32 required buck converters and careful power distribution to prevent overload or overheating.

7.1.3 Bluetooth Connectivity Issues

Maintaining a stable connection between the mobile app and the robot via Bluetooth was sometimes unreliable due to interference or network congestion.

7.1.3 QR Code Scanning Accuracy

Challenges like camera angle, lighting, and QR code placement affected scan consistency and speed, requiring calibration and OpenCV tuning.

7.1.4 Audio Output Delays

Real-time voice output using TTS tools (gTTS/espeaK) occasionally caused delays or stutters, especially during large data processing.

7.1.6 Database Access and Latency

Retrieving project information from MySQL or JSON sources needed optimization to ensure quick and smooth user experience.

7.1.7 User Interface Design

Developing a clear, user-friendly interface for the 10.1" touchscreen required careful attention to layout, readability, and responsiveness.

7.1.8 Mechanical Balancing with Mecanum Wheels

Achieving accurate motion required precise synchronization of all wheels, which was difficult without encoder feedback or motion correction logic.

7.2 FUTURE ENHANCEMENT

7.2.1 Autonomous Navigation

Integrating sensors like LiDAR, ultrasonic modules, and SLAM (Simultaneous Localization and Mapping) technology to enable obstacle detection and autonomous movement, eliminating the need for manual control.

7.2.2 Interactive Tour Selection

Allowing users to stop the robot at any project station or move to the next one using the "Move Forward" button on the robot's screen. Users can also select between a "Detailed Tour" or a "Brief Tour" based on their preference and time availability.

7.2.3 Autonomous Camera Adjustment: Implementing a rotating camera mechanism that automatically adjusts angles to locate and scan QR codes more efficiently.

7.2.4 Multilingual Support: Enabling the robot to present information in multiple languages (such as English, Hindi, Gujarati, etc.), increasing accessibility and user understanding.

7.2.5 Cloud-Based Data Access

Hosting the project database on cloud platforms like Firebase for real-time data updates, remote access, and simplified data management.

7.2.6 Object Detection and Recognition

Using AI and computer vision models to recognize lab equipment and project components, offering explanations without relying solely on QR codes.

7.2.7 Battery Monitoring System

Adding a real-time battery level monitoring system with alerts to ensure uninterrupted robot operation and timely recharging.

7.2.8 Chatbot Integration

Introducing a chatbot to answer user queries related to projects, components, and lab details, enhancing the robot's interactivity and educational value.

Incorporating a feedback interface on the display screen to allow visitors to share their experiences, suggestions, and reviews about the robot, individual projects, and the overall lab setup—helping improve future exhibitions and user satisfaction.

CONCLUSION

The Lab Assistant Robot successfully addresses the challenges faced by visitors in understanding and exploring laboratory projects during exhibitions or open days. By integrating technologies like QR code scanning, audio output, and a user-controlled mobile app, the robot offers an interactive and self-guided experience. It eliminates the need for human assistance while providing clear and engaging project information. The combination of ESP32 and Raspberry Pi, along with a touchscreen interface and Bluetooth communication, ensures smooth control and user interaction. Although challenges such as hardware integration, connectivity, and scan accuracy were encountered, they provided valuable learning experiences and were overcome through testing and optimization. Overall, the project demonstrates a practical application of AI, IoT, and robotics to enhance educational outreach and visitor engagement within a laboratory environment.

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