An-Najah National University

Faculty of Engineering and Information Technology
Department of Computer Engineering

Graduation Project II
CleanItAll: Hypred Cleaning Robot

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Dedication:

This project is dedicated to our families, whose unwavering support and encouragement have been our guiding light. To our parents, for their endless sacrifices and belief in us, and to our friends for their understanding and patience throughout this journey. We also dedicate this work to the students of Gaza, whose educational journeys have been disrupted by the war. Lastly, we dedicate this project to our supervisor, Dr. Anas Toma, whose guidance has been invaluable.

Acknowledgments:

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Disclaimer:

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Abstract:

This report presents the design, development, and implementation of *CleanItAll*, an innovative multifunctional cleaning robot that enhances the capabilities of existing robotic vacuum cleaners by integrating both cleaning and object-handling functions. The primary objective was to build a cost-effective, autonomous cleaning solution that can efficiently vacuum, mop, and pick up larger objects such as bottles using a robotic arm. This addresses a key limitation in most current consumer cleaning robots.

The *CleanItAll* robot features multiple cleaning mechanisms, including side brushes, a central rotating brush, a vacuum system, and dual mopping pads, enabling it to handle various debris types across different surfaces. Navigation is controlled via a Zigzag movement pattern using ultrasonic sensors for obstacle avoidance and an IR sensor for anti-fall protection. The robot also includes an OAK-D camera for real-time object detection and distance measurement, allowing it to detect and remove larger objects through the robotic arm. A custom-built, fully responsive web interface was developed to allow users to monitor and control the robot remotely, providing full access to its various components and functionalities. This interface can be accessed on both desktop and mobile devices, ensuring ease of use and control.

The robot was built using a combination of hardware, including Arduino and Raspberry Pi, and the cleaning and navigation systems were carefully programmed to ensure autonomous operation. Testing demonstrated high accuracy in obstacle detection, with the robot avoiding obstacles and adjusting its path. The object detection system performed well, with the robot accurately recognizing and removing objects like bottles. The cleaning system was particularly effective on both tile and wood surfaces.

The project was successful in achieving its goals, with tests showing high accuracy in navigation, object detection, and cleaning performance, particularly on wood and tile surfaces. While limitations such as time constraints and minor issues with the camera’s distance accuracy were encountered, the robot performed well overall. The project demonstrates the feasibility of combining affordable robotics components with advanced cleaning mechanisms to create an accessible, user-friendly, and effective cleaning solution.

Introduction:

Background:

The rapid advancement in technology has led to significant improvements in household appliances, especially in the realm of automated cleaning solutions. Robotic vacuum cleaners have emerged as a revolutionary product, offering convenience, efficiency, and advanced features that cater to modern households. These devices leverage cutting-edge technologies such as artificial intelligence, machine learning, and advanced sensor systems to perform cleaning tasks autonomously, reducing the manual effort required for maintaining cleanliness in homes and offices.

Objectives:

The primary objective of this project is to design and develop a multifunctional cleaning robot equipped with a robotic arm for handling larger objects, which sets it apart from existing models. The project aims to achieve the following specific goals:

- Integrate a simple yet effective robotic arm to pick up and remove relatively larger objects that standard robotic vacuums cannot handle.
- Incorporate a comprehensive cleaning mechanism that includes a front brush, a rotating brush, and two mopping pads at the back, providing versatile cleaning modes.
- Utilize a straightforward navigation system primarily based on ultrasonic and IR sensors to enable the robot to avoid obstacles and navigate effectively.
- Enhance the suction and cleaning mechanisms to ensure thorough removal of dust and debris.
- Provide a user-friendly interface through web page for easy control and monitoring of the cleaning process.

Significance:

This project addresses key challenges in existing robotic vacuum cleaners by incorporating a robotic arm and versatile cleaning modes. The robotic arm allows the cleaner to pick up larger debris, ensuring a more thorough cleaning process. The combination of a front brush, a rotating brush, and dual mopping pads enhances versatility, adapting to various flooring types and cleaning needs.

Using a simple navigation system with ultrasonic and IR sensors, along with a zig-zag movement pattern, ensures reliable performance without high costs. This makes the robot accessible to a broader market, including budget-conscious consumers. Overall, the project advances robotic cleaning technology by offering a product that is affordable, functional, and user-friendly, meeting the demand for smart home devices that balance cost and performance.

Organization of the report:

This report is organized into several sections to comprehensively cover the design, development, and testing of the *CleanItAll* robot:

1. **Introduction**: Provides an overview of the project, its objectives, and significance.
2. **Literature Review**: Discusses the evolution of robotic vacuum cleaners and key technologies used in modern systems.
3. **Methodology**: Details the hardware components, procedures, and techniques employed in building and programming the robot.
4. **Website for Robot Control**: Describes the design and features of the web interface used to control and monitor the robot.
5. **Communication Protocols**: Explains the data exchange between the Arduino and Raspberry Pi for robot control.
6. **Results and Analysis**: Presents data collected from the robot's sensors and evaluates its performance in cleaning and object handling.
7. **Discussion**: Summarizes key contributions, limitations, and comparisons with existing technologies.
8. **Conclusion and Recommendations**: Concludes the report by summarizing the results and offering suggestions for future improvements.

Literature Review:

Overview of Robotic Vacuum Cleaners

Robotic vacuum cleaners have evolved significantly since their inception. Early models, like the Electrolux Trilobite and iRobot Roomba, were limited by basic navigation systems and cleaning capabilities. Today, robotic vacuums leverage advanced technologies such as LiDAR, artificial intelligence (AI), and multi-function cleaning systems, significantly enhancing their efficiency and versatility.

Key Developments and Technologies

Navigation Systems:

- Early Models: Initial robotic vacuums relied on simple bump sensors and random navigation patterns, often resulting in inefficient cleaning routes.

- Modern Advances: Current models utilize technologies such as LiDAR, cameras, and infrared sensors to create precise maps of their cleaning areas, enabling systematic navigation and effective obstacle avoidance, enhancing cleaning efficiency and coverage (Gizmo Cleaning, 2023; Owner's Magazine, 2023).

- Smart Mapping: Advanced mapping capabilities enable users to customize cleaning schedules and target specific areas, providing greater control and flexibility in the cleaning process (Owner's Magazine, 2023).

Cleaning Mechanisms:

- Initial Designs: Early models had basic suction capabilities and a single rotating brush, limiting their cleaning effectiveness.

- Enhanced Mechanisms: Modern vacuums feature dual brushes, stronger suction motors, and adaptability to various floor types, ensuring thorough cleaning. Some models also incorporate mopping functions, offering a comprehensive cleaning solution (Gizmo Cleaning, 2023; Owner's Magazine, 2023; Srhythm, 2023).

AI and Machine Learning:

- Adaptive Learning: AI-powered robots can learn and adapt to their environments, optimizing their cleaning routes over time for improved efficiency. Examples include the iRobot Roomba j7 and s9, which offer advanced obstacle avoidance and effective corner cleaning (Srhythm, 2023).

- Advanced Features: Features such as automatic dirt disposal, zone cleaning, and real-time notifications enhance user convenience and cleaning performance (Owner's Magazine, 2023; Srhythm, 2023).

Robotic Arms:

Emerging Integration: The integration of robotic arms in consumer products is still emerging but promises to enhance functionality by enabling the handling of larger debris. This research focuses on simplifying design for cost-effective production and practical home use (Gizmo Cleaning, 2023; Owner's Magazine, 2023).

Previous Work

Several studies and projects have laid the groundwork for the development of modern robotic vacuum cleaners:

Path Planning and Navigation**:**

- Research by Thrun et al. has contributed foundational knowledge in probabilistic robotics, influencing current path planning algorithms.

- Advances in simultaneous localization and mapping (SLAM) have been critical in enabling autonomous navigation in complex environments (Gizmo Cleaning, 2023; Owner's Magazine, 2023).

Sensor Integration:

Siegwart and Nourbakhsh explored the application of various sensors in mobile robotics, informing the design of modern navigation systems (Gizmo Cleaning, 2023).

Cleaning Efficiency:

Studies on brush design and suction efficiency have led to the development of more effective cleaning mechanisms. Research into mopping functions has expanded the capabilities of robotic cleaners (Gizmo Cleaning, 2023; Srhythm, 2023).

Robotic Arms:

Research into affordable and efficient robotic arms aims to enhance the functionality of consumer products without significantly increasing costs, focusing on practical home applications (Gizmo Cleaning, 2023; Owner's Magazine, 2023).

Methodology:

Project Overview

The "CleanItAll" is a comprehensive and innovative cleaning robot designed to autonomously navigate and clean various surfaces. The robot is equipped with multiple cleaning mechanisms, including side brushes, a central brush, a vacuum motor, and a mop system, to ensure thorough cleaning. Additionally, it has an integrated robotic arm for handling larger debris, and a camera system for object recognition. The robot is rechargeable and includes a battery indicator and a charging socket.

Experimental Setup

Hardware Components:

- Arduino Mega: Acts as the central hub for all sensor connections, ensuring efficient data acquisition and processing.

- Raspberry Pi 4 Model B: Responsible for the control of the camera and the robotic arm, providing the necessary computational power for real-time image processing and object detection.

- Motors:
  - Two 5V DC motors: Power the front brushes for sweeping debris into the central cleaning path.
  - 12V DC motor: Drives the central brush located underneath the robot, ensuring deep cleaning of surfaces.

    - 12V DC gear motor: Powers one of the two mops at the back of the robot.
    - 3D Printed Gear: Facilitates the movement of the second mop by connecting it to the first through the gear mechanism.
    - 12V DC Valve: Controls water flow to the mops, ensuring precise and efficient cleaning.
    - Two Stepper Motors: Enable precise central movement of the robot, allowing it to navigate complex paths.
    - Two Stepper Motor Drivers: Provide the necessary control and power to the stepper motors.

- 4-Channel Relay: Manages the power supply to the main components, ensuring coordinated operation of the cleaning system.

- Sensors:
    - Ultrasonic Sensors: Five sensors placed at strategic points (front, right, left, and at 45-degree angles on both sides) for obstacle detection and navigation.
    - IR Sensor: Positioned under the robot as an anti-fall mechanism, particularly useful for detecting stairs.

- OAK-D Camera: A high-definition camera used for object recognition, particularly identifying and locating bottles.

- Servo Motors:
    - Two Servo Motors: Control the angles of the robotic arm, providing three degrees of freedom (3 DOF).
    - One Servo Motor: Controls the gripper of the arm for handling objects.

- Battery Indicator: Provides real-time feedback on the battery status, ensuring timely recharging.

- 12V Battery and Charger: The main power source and charging solution for the robot.

- Main Switch: Serves as the master on/off switch, ensuring user control over the robot's operation.

Procedures and Techniques

The development of "CleanItAll" followed a systematic approach, broken down into the following stages:

Main Body Construction:

The robot's main body was constructed from three primary sections: the base, the height, and the upper cover. The base and upper cover were made from a special lightweight wood that was selected for its ability to withstand weight and pressure, ensuring durability without adding unnecessary bulk. The height was crafted from Alcabond aluminum plates, chosen for their flexibility and ability to be shaped into a circular form, providing structural integrity while maintaining a sleek design.

Wheel and Stepper Motor Installation

Following the construction of the main body, the next step was to install the wheels and connect them to the stepper motors. This stage required the creation of custom 3D-printed couplers to connect the wheels to the stepper motors effectively. This ensured smooth and precise movement, allowing the robot to navigate various terrains with ease.

Sensor Integration and Movement Programming

The robot was equipped with five ultrasonic sensors and one IR sensor to facilitate navigation and obstacle detection. The ultrasonic sensors were strategically placed to cover all directions (front, left, right, and at 45-degree angles on both sides). The IR sensor, positioned underneath the robot, acts as an anti-fall mechanism, particularly useful for preventing falls down stairs. The main movement code, which controls the robot’s navigation in a Zig-Zag pattern, was written and implemented in Arduino.

Cleaning System Construction

The cleaning system was a critical component of the robot, involving the installation of two side brushes, the central brush, the vacuum motor, two back mops, a water valve, and the dirt container. The 12V DC valve was integrated to control the water supply to the mops, ensuring efficient cleaning. A relay was used to coordinate the operation of these components, allowing for synchronized and efficient cleaning.

Arm Construction

The robotic arm was constructed from wood and provided with three degrees of freedom (3 DOF). It was then connected to the main body of the robot. The arm is designed to pick up larger objects, such as bottles, which are detected by the camera system. The arm's movements were programmed to perform a series of actions based on the distance and position of the detected object.

Camera and Object Recognition Integration

The final stage involved integrating the OAK-D camera and the object recognition system with the Raspberry Pi. The camera's feed is processed in real-time to detect objects, particularly bottles, which the robotic arm then handles. This integration was crucial for the robot's autonomous operation and was distributed throughout the development process to ensure seamless functionality.

Constraints

Budget Constraints

The project faced significant budgetary constraints due to the high cost of components, particularly the LDR sensor, which was also difficult to source locally. This limited the range of components available for use, requiring careful consideration and prioritization of essential features.

Time Constraints

Time was another critical constraint, as the project timeline was tight. The team often had to work late into the day at the university to meet deadlines and ensure the project progressed on schedule. This required efficient time management and prioritization of tasks to ensure all critical aspects of the project were completed.

Sucker System Challenges

One of the major challenges was finding a suitable motor for the vacuum system that could effectively suck dirt and debris. Several motors were tested, but many were found to be too weak for the task. The issue was eventually resolved by sourcing a more powerful motor that met the required specifications.

Sustainability and Manufacturability

Sustainability Considerations

The robot’s design posed a significant challenge in terms of sustainability due to its size and the need for special, customized components. This was essential to ensure that the robot could move freely and operate effectively. The use of recyclable materials, such as Alcabond aluminum plates, which are 100% recyclable, was a conscious decision to minimize the environmental impact of the project.

Manufacturability Challenges

The manufacturability of the robot was closely tied to its size, which required customized components. This customization was crucial for the robot's functionality but also posed challenges in sourcing and producing these parts. The team had to carefully design and 3D-print certain components, such as the couplers for the wheels and stepper motors, to ensure the robot's seamless operation.

Health and Safety

Safety Protocols

Safety was a priority throughout the project, with each component being tested individually upon connection. The robot was designed with common grids for Vcc (5V), GND, and 12V to ensure consistent and safe power distribution. After adding each new component, tests were re-applied to confirm the safety and proper operation of the system.

Risk Assessment

The water container for the mops was a particular focus of the risk assessment. Although the container was well-insulated, there was room for improvement by designing a customized container that would allow the valve tip to be more securely attached. This would enhance the safety and reliability of the water delivery system.

Safety Features

Several safety features were incorporated into the robot's design. An IR sensor was installed underneath the robot to act as an anti-fall mechanism, preventing the robot from falling off stairs or other elevated surfaces. Additionally, a master switch was included for emergency shutdowns, and the robot can also be stopped via a mobile application developed specifically for remote control.

Data Collection and Analysis

Data Sources

The robot collects data from five ultrasonic sensors and one IR sensor. The ultrasonic sensors provide readings from the front, right, left, and 45-degree angles on both sides, while the IR sensor is used for the anti-fall mechanism. Additionally, the camera captures visual data that is processed in real-time by the Raspberry Pi for object detection, specifically focusing on identifying bottles. The object recognition system utilizes the

MobileSSD module, and the OAK-D camera provides high-definition video feed for this purpose.

Tools and Software

Data analysis was conducted using the Arduino IDE for processing sensor data and controlling the robot's movements. A Python IDE was used for the Raspberry Pi, which handled the camera feed and object recognition. The integration of these tools allowed for real-time analysis and decision-making by the robot.

Theoretical Background

Application of Theory

The theoretical foundation of the project includes principles of robotics, object detection, and control systems. A pre-trained model was collected as a. blob file and utilized in a Python script to run the camera. The model was customized to detect specific objects, such as bottles, and to provide information on their distance and position relative to the robot. The robot's arm movements were designed based on the distance of the object, using a sequential process to grip and remove the object effectively.

Ethical and Environmental Considerations

Ethical Issues

The project took into account privacy concerns associated with the camera. To protect privacy, the camera does not store or record any video; instead, it processes the visual data in real-time solely for detecting objects. This ensures that the robot operates ethically, respecting individuals' privacy.

Environmental Impact

The materials used in the robot, particularly the Alcabond aluminum plates, were selected with environmental sustainability in mind. These plates are 100% recyclable, reducing the environmental footprint of the project and contributing to a more sustainable design.

Website for Robot Control and Monitoring

The CleanItAll robot features a fully functional and user-friendly website designed to allow users to control and monitor the robot efficiently. The website plays a crucial role in providing a seamless interface for interacting with the robot, offering a wide range of control options while ensuring ease of use. Built with both desktop and mobile users in mind, the site is responsive, adjusting to different screen sizes without relying on heavy frameworks like Bootstrap or Tailwind.

Website Features and User Controls

The website is designed to give users complete control over the robot's functionality. The primary controls available include:

1. **Power On/Off Control**: Users can remotely power the robot on or off, providing full management of the robot's operation from the convenience of their device.
2. **Component Monitoring**: The website displays the status of all the robot's main components, including the motors. Users can monitor the activity of each component in real time, ensuring they can assess whether the robot is functioning as expected.
3. **Motor Control**: In addition to monitoring, the website allows users to control the status of each motor individually. This includes not only the motors driving the wheels and cleaning mechanisms but also the motors controlling the robotic arm. Users can activate or deactivate each motor based on the task at hand.
4. **Turbo Sucker Control**: The turbo sucker, a critical component for handling more intense cleaning tasks, can be activated or deactivated through the website, giving the user control over the cleaning power based on the environment.
5. **Speaker Control**: A speaker is integrated into the robot, and the user can adjust the sound level or turn the speaker on/off directly from the website.
6. **Alerts and Warnings**: The website is designed to be reliable and user-friendly, incorporating warnings and alerts when necessary to notify the user of any potential issues, such as low battery or component malfunctions.

Website Structure and Pages

The website is divided into three main sections:

1. **Main Page**:

   The Main Page provides an overview of the robot's current status. It displays key information such as the power state, battery level, and the status of each main component. This page serves as the primary dashboard for monitoring the robot's overall health and activity.

2. **Settings Page**:

   The Settings Page is where the user can take full control over the robot's components. This includes toggling the motors on or off, controlling the turbo sucker, and adjusting the speaker's sound level. Users can easily modify the robot's settings based on the task at hand, with Session Storage ensuring that the current and default settings are stored for future use.

3. **Manual Control Page**:

   - The Manual Control Page offers advanced control options, allowing users to operate the robot manually. This page is divided into two sections:
     - **Movement Control**: Users can control the entire robot's movement, including commands for forward, backward, left, right, and rotational movement.
     - **Arm Control**: Users can also manually control each motor in the robotic arm, giving them the freedom to manipulate objects and perform specific tasks with precision.
   - This manual control mode offers complete flexibility, allowing the user to interact directly with the robot as needed, whether for cleaning or object manipulation.

Responsive Design

One of the key features of the website is its responsiveness. The website was built using MediaQuery, ensuring it adjusts seamlessly to different screen sizes, from desktop computers to mobile devices. This is crucial for users who wish to monitor and control the robot while on the go, providing them with the flexibility to manage the robot from their mobile devices without losing functionality or clarity.

Technology Stack

The website's design and functionality are supported by a combination of technologies to ensure smooth performance and interactivity:

- **Client-Side Technologies**: The front end of the website is built using standard web technologies: HTML, CSS, and JavaScript. This ensures that the website is lightweight, fast, and easily accessible from any modern web browser.
- **Client Backend (JavaScript)**: The client-side logic, including user interactions and control of the robot's components, is handled by JavaScript. This allows for a dynamic and interactive user experience without needing to reload the page constantly.
- **Server Backend (Python)**: The back-end server logic is written in Python, providing the necessary processing power to handle requests from the client and send commands to the robot. Apache Server is used for local deployment, ensuring reliable communication between the user's device and the robot.
- **Session Storage**: The website uses Session Storage to maintain the robot's current status and user settings. This allows the website to store and recall default and current settings, providing a more consistent and personalized experience each time the user interacts with the robot.

User Experience

The website for CleanItAll is designed with a strong focus on usability. Its intuitive interface ensures that users of all skill levels can interact with the robot without needing extensive technical knowledge. The inclusion of alerts and warnings further enhances the user experience, ensuring that any critical issues with the robot are immediately communicated to the user. Whether it's monitoring the robot's performance or manually controlling its movements, the website ensures that the user always remains in control.

Images from the website:

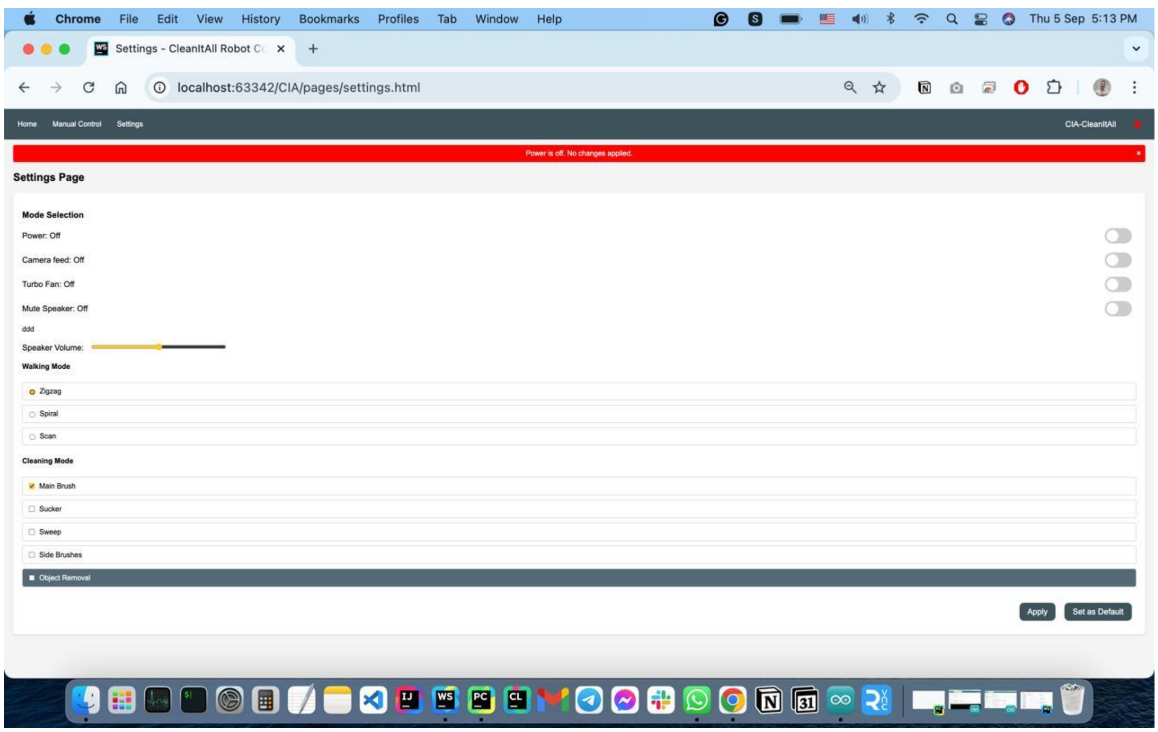

Figure 1: Robot Control Settings Page Interface (Website Version)

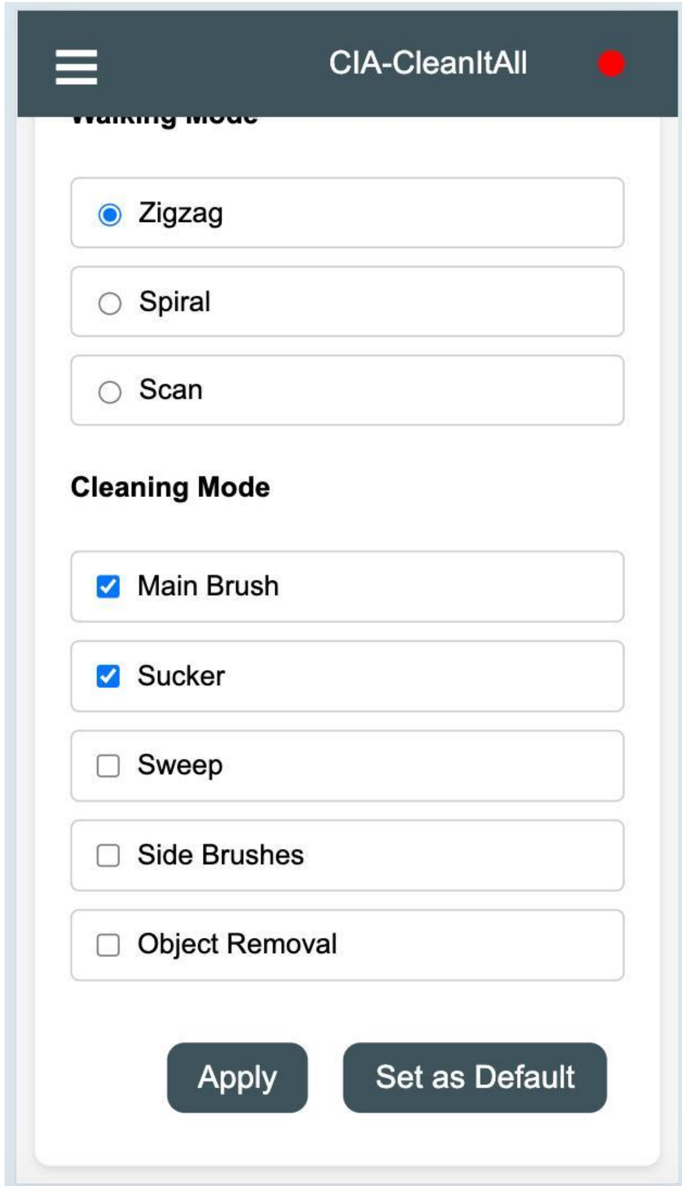

Figure 2: Robot Control Settings (Mobile Version)

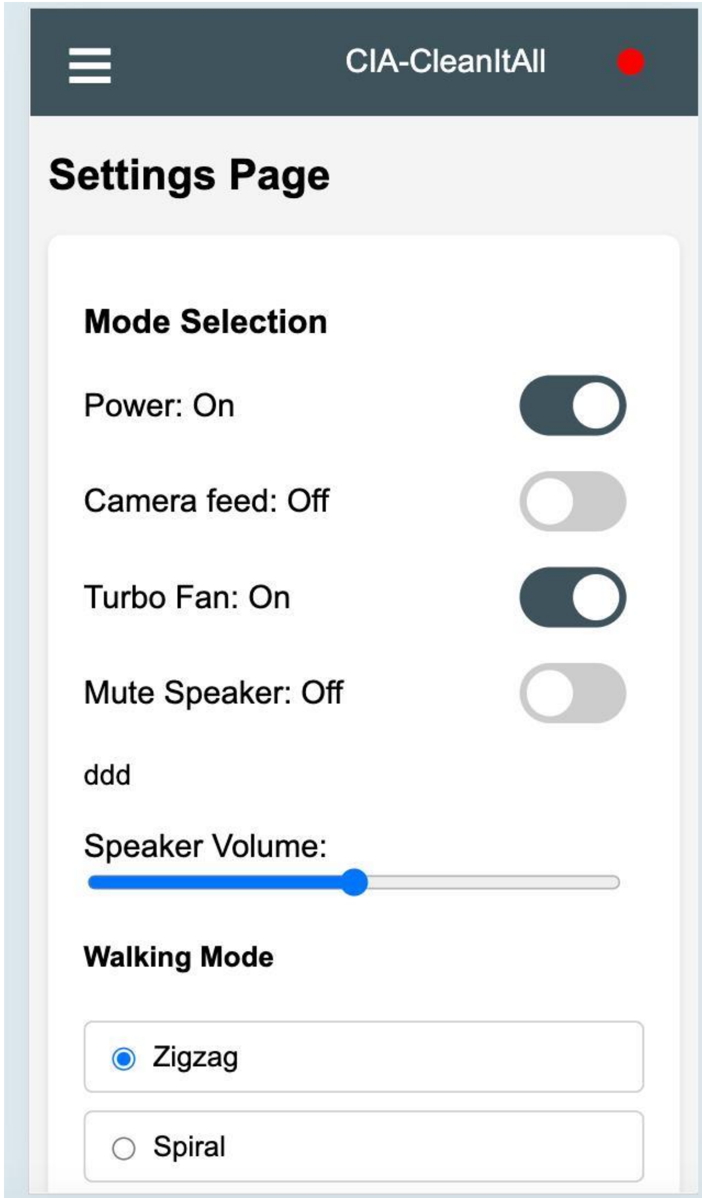

Figure 3: Robot Settings Page with walking Mode Selection (Mobile Version)

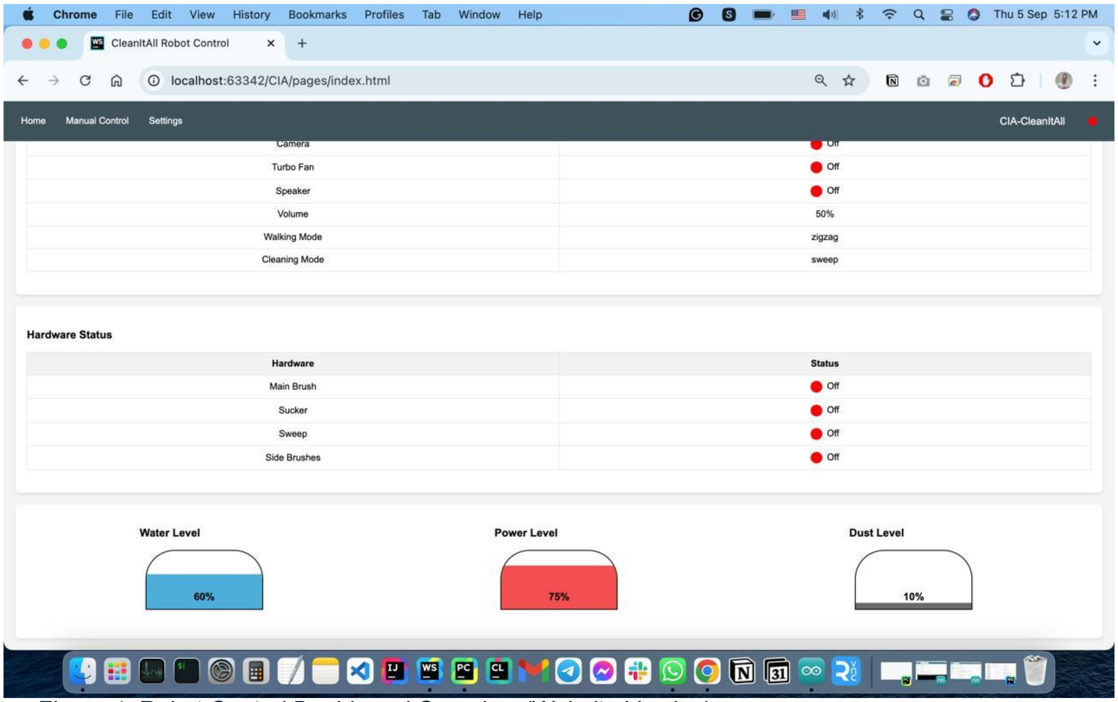

Figure 4: Robot Control Dashboard Overview (Website Version)

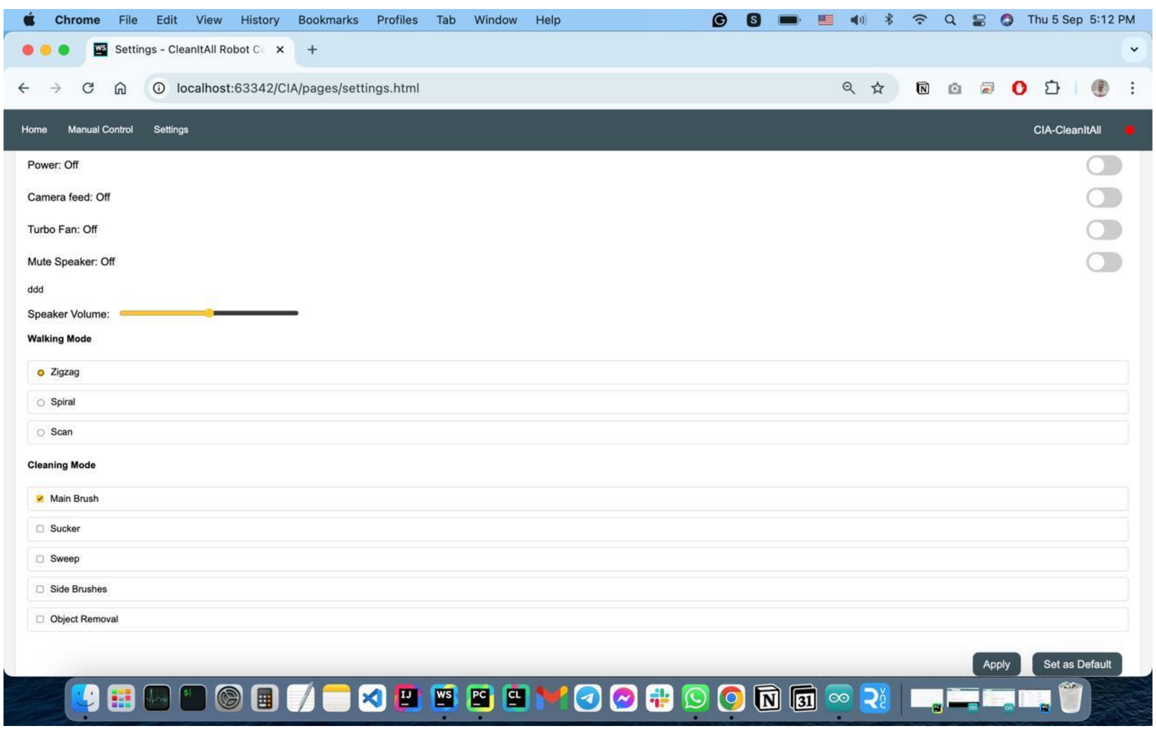

Figure 5: Robot Control Settings with Walking and Cleaning Modes (Website Version)

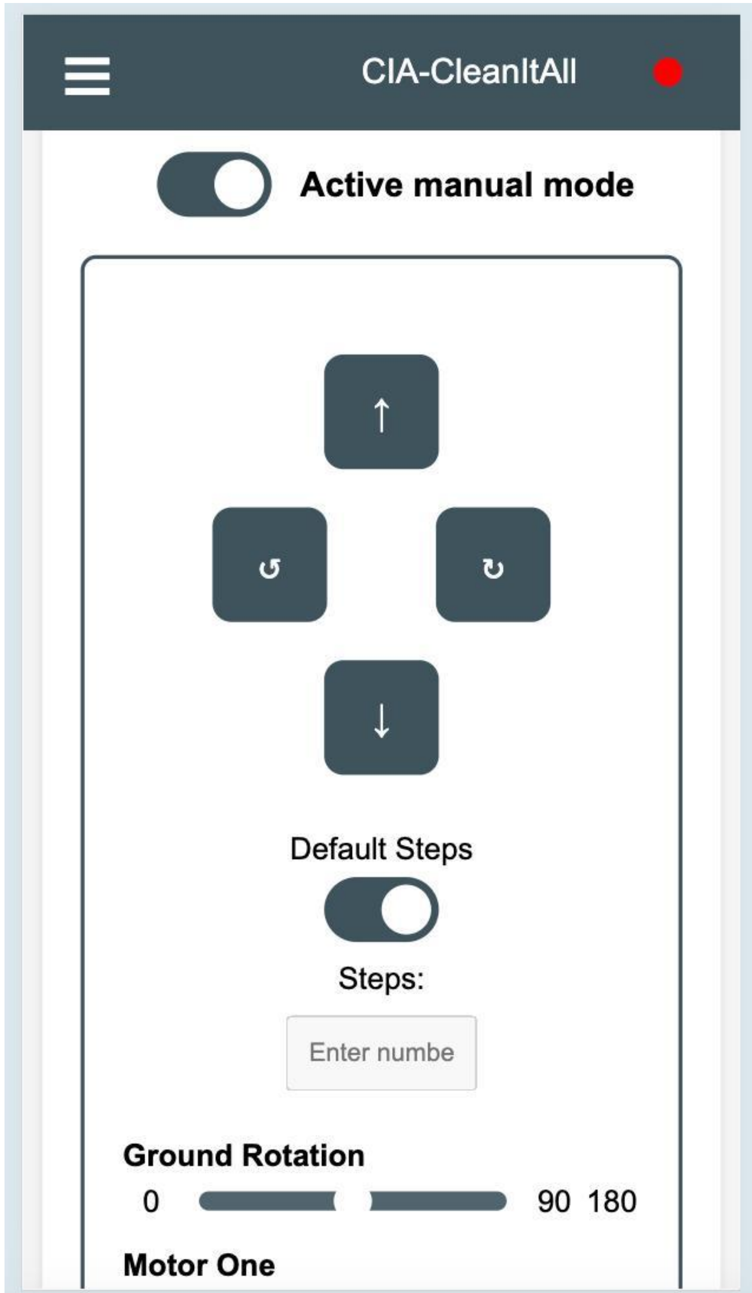

Figure 6: Manual Control Interface for Robot Movement (Mobile Version)

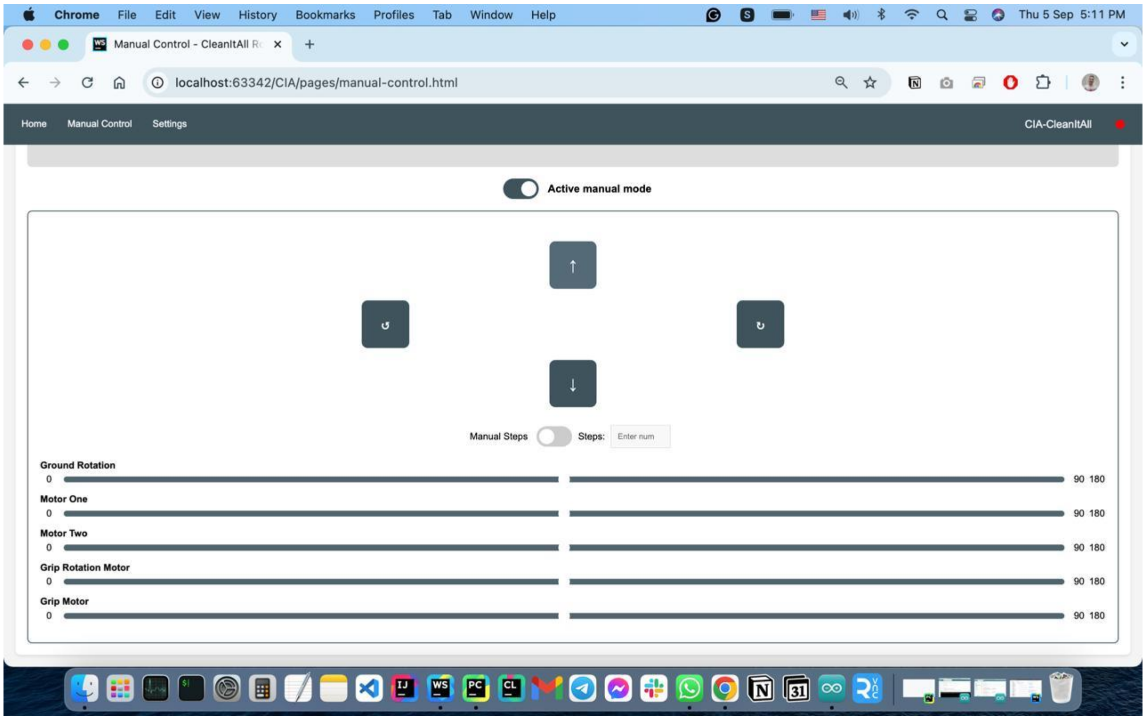

Figure 7: Manual Control Interface with Motor Adjustments (Website Version)

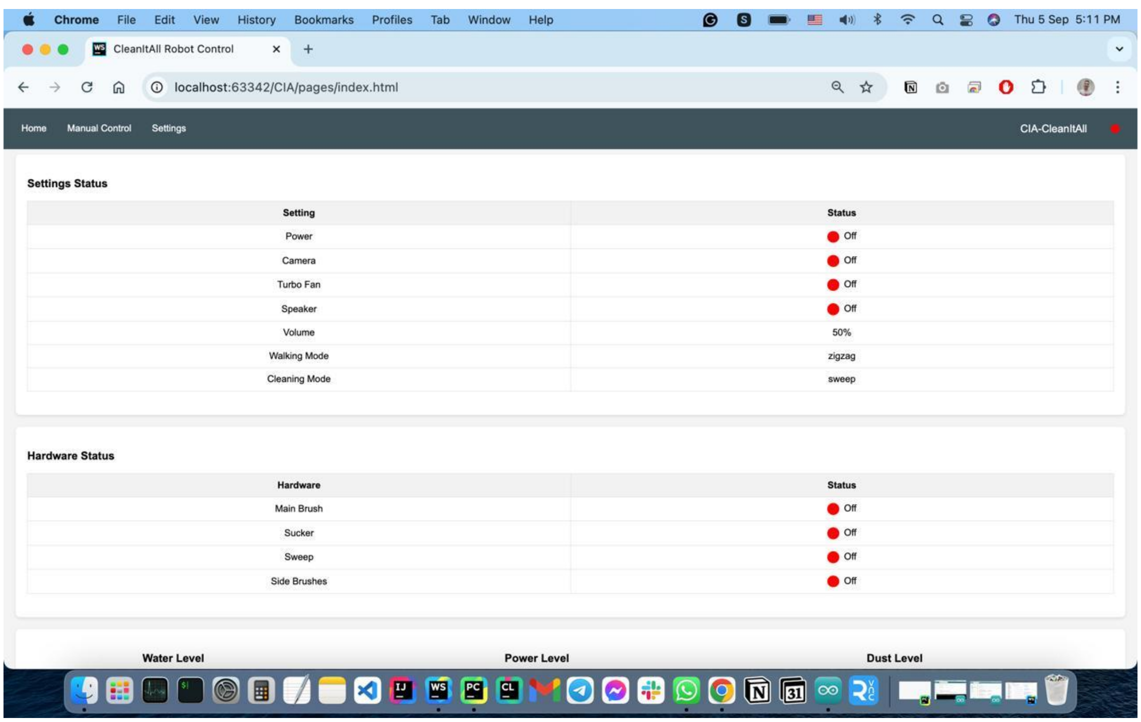

Figure 8: Robot Control Dashboard with Settings (Website Version)

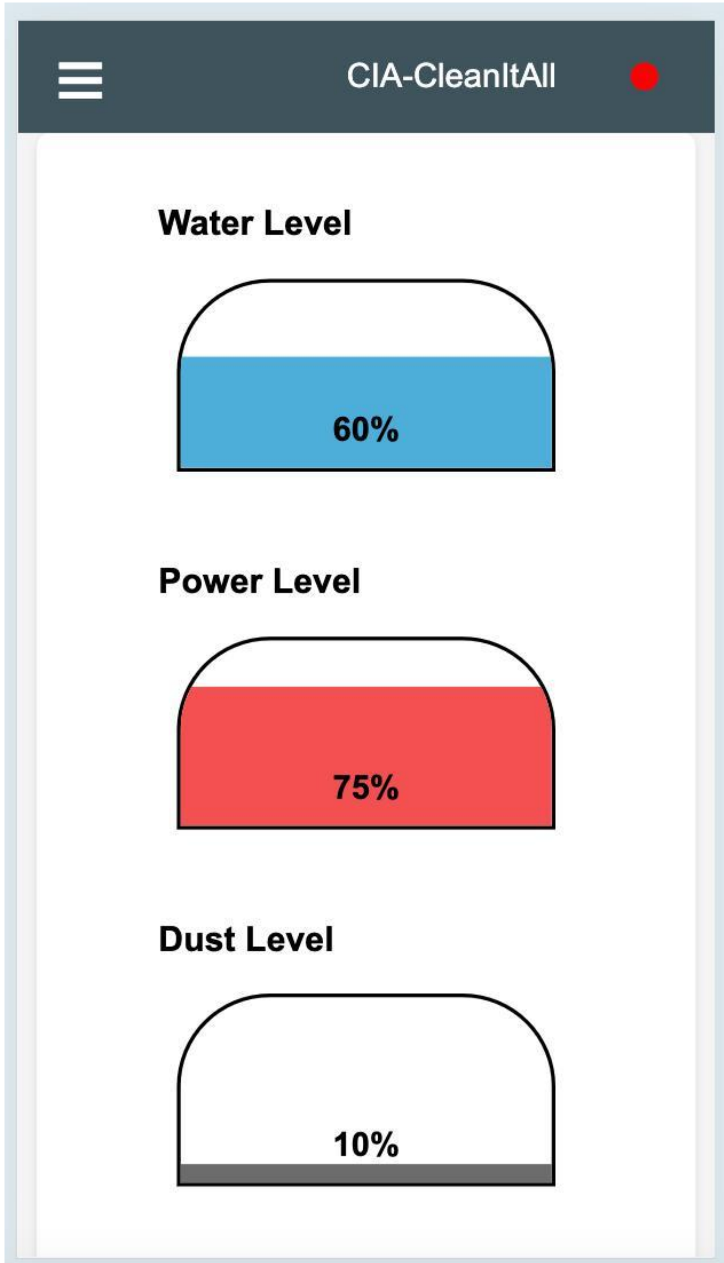

Figure 9: Water, Power, and Dust Level Indicators (Mobile Version)

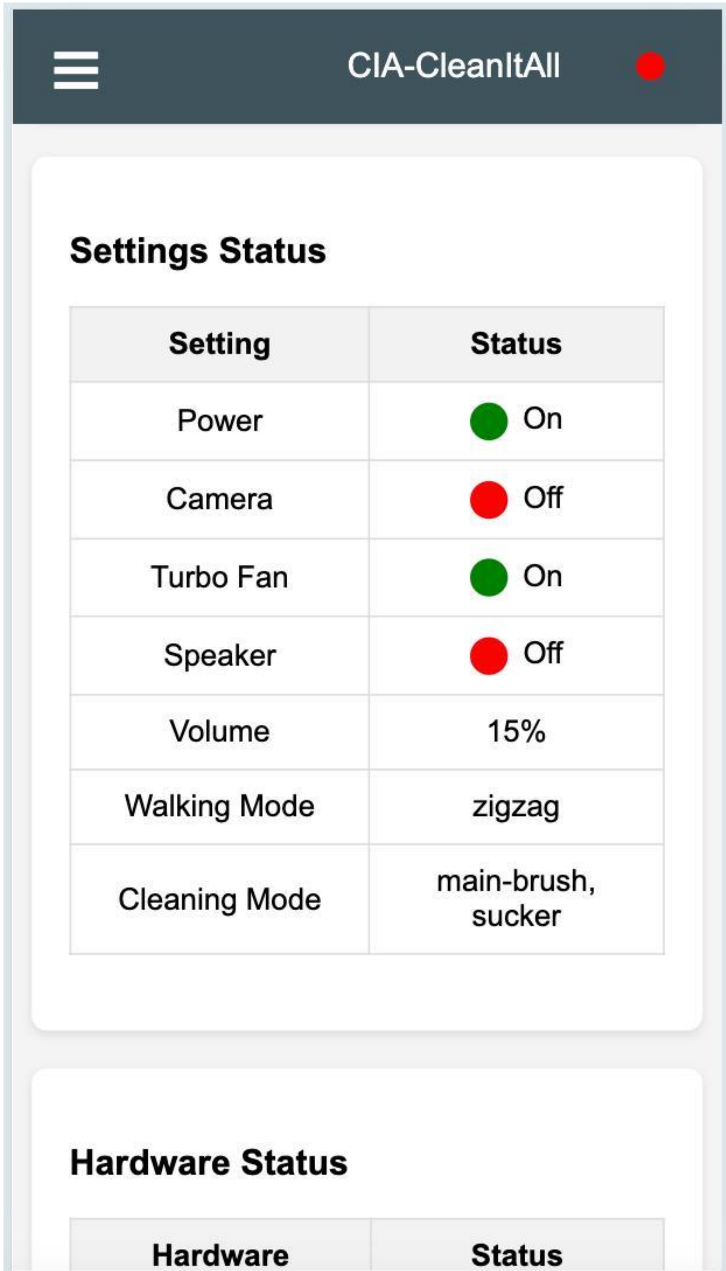

Figure 10: Robot Settings and Hardware Status Overview (Mobile Version)

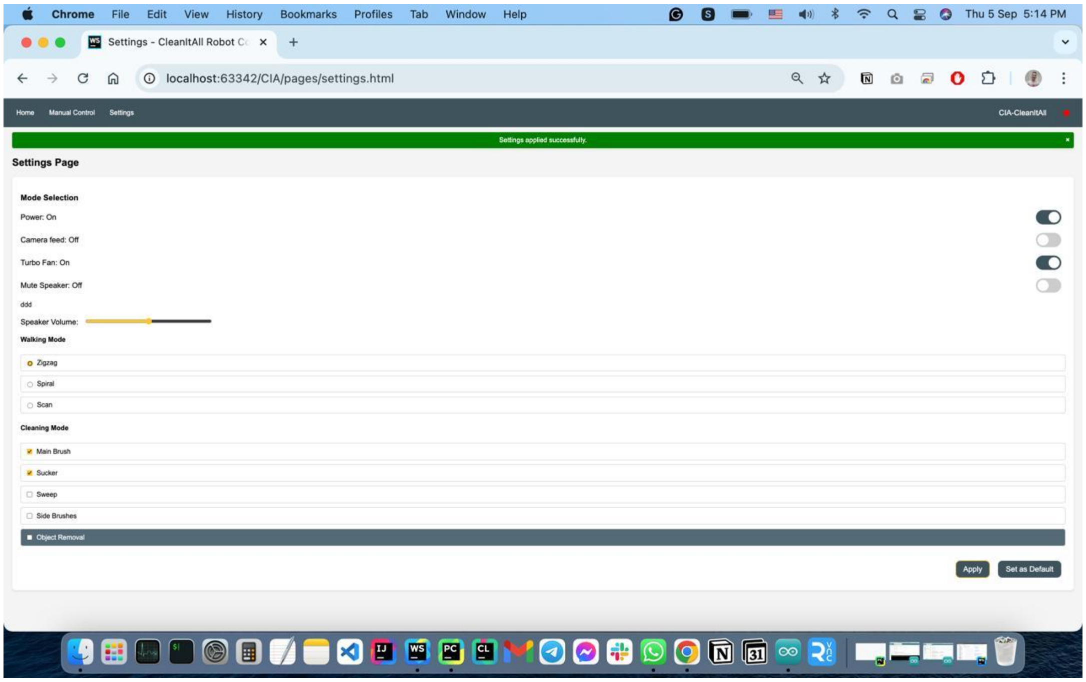

Figure 11: Robot Control Settings Page with Successful Settings Update (Website Version)

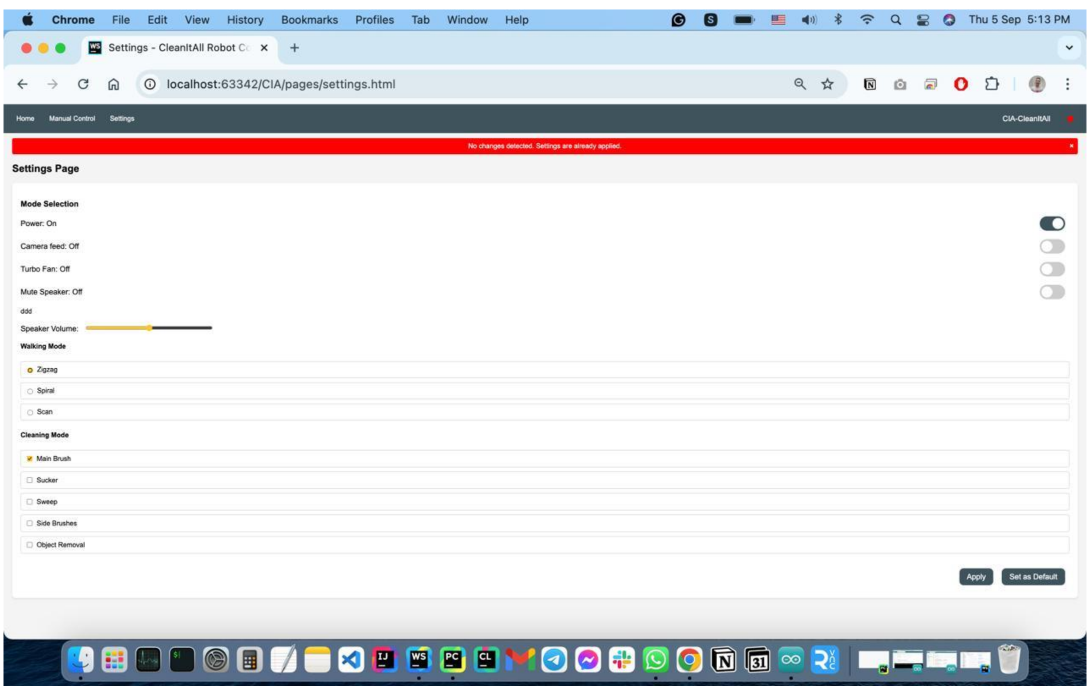

Figure 12: Robot Control Settings Page with Successful Settings Update (Website Version)

Communication Protocols Between Arduino and Raspberry Pi

The communication between the Raspberry Pi and Arduino in the CleanItAll robot is handled through a UART (Serial) protocol, established by directly connecting the Arduino to the Raspberry Pi using the Arduino's USB cable. This setup allows for reliable data transfer between the two devices, enabling smooth coordination of the robot's various systems.

Communication Protocol and Data Exchange

1. **Protocol Used:**
   The UART (Serial) protocol is the core of the communication between the Raspberry Pi and the Arduino. This simple and effective communication method allows the Raspberry Pi to send and receive commands from the Arduino over a USB connection.

2. **Data Exchange:**
   The data exchanged between the Raspberry Pi and Arduino covers a wide range of operations and commands, including:

   - **Control Commands**: Commands that dictate the robot's movements (e.g., moving forward, backward, turning, etc.).
   - **Settings Commands**: Commands that set specific parameters for the robot, such as activating the turbo fan, adjusting the speaker volume, or enabling/disabling the camera.
   - **Robot Status**: Messages sent from the Arduino to the Raspberry Pi to relay the current status of various components.
   - **Object Pick-Up Commands**: Automated commands to activate the robotic arm for object pick-up once an object is detected by the camera.
   - **Power Status Detection**: The Raspberry Pi is informed of the robot's power status, particularly when the main power switch is turned on or off.

Power Synchronization

To ensure synchronization between the main power and the Arduino’s execution, a wire is connected from the main power supply (after being regulated to 5 volts) to the Arduino. This connection allows the Arduino to detect when the main power is on, ensuring that the code execution begins as soon as the power is detected. This feature helps in synchronizing the robot's overall system behavior, ensuring the Arduino and Raspberry Pi operate in tandem.

The system also includes a WatchDogTimer, which is used to monitor the Arduino’s execution and ensure the smooth operation of its code in relation to the main power status. This provides an added layer of reliability, ensuring that any power interruptions or miscommunication are promptly addressed.

Error Handling and Message Structure

To ensure robust communication, error handling mechanisms are built into the communication system. These mechanisms include:

- **Acknowledgments**: For certain critical commands, an acknowledgment system is implemented to verify that the Raspberry Pi and Arduino successfully transmit and receive messages. This ensures that the system remains synchronized and that commands are executed as intended.
- **Structured Message Format**: All messages exchanged between the Raspberry Pi and Arduino follow a structured format. This format allows the receiving system to quickly interpret the nature of the message and act accordingly. The message is checked upon receipt to determine the command type, status update, or setting adjustment.

Results and Analysis:

Data Collected

Sensor Data:

The robot's navigation and cleaning functionality relied heavily on the accurate performance of its sensors. The primary mode of movement was the Zigzag pattern, which was guided by the ultrasonic sensors placed at the front, right, and left of the robot.

Ultrasonic Sensors: The readings from the ultrasonic sensors were consistently accurate, with no false detections reported during testing. Obstacles were identified in all trials, ensuring the robot could adjust its path without incident. While the testing showed no inaccuracies, it is acknowledged that under certain conditions, the sensors might experience issues not encountered during these tests.

IR Sensor: The IR sensor, which prevents the robot from falling down stairs, was adjusted to trigger at 4 cm. This adjustment was effective, with no cases of failure or incorrect readings during tests.

Camera (OAK-D): The camera, which handles object detection, performed with 100% accuracy in detecting both plastic and aluminum bottles during testing. While it provided real-time data on the distance between the robot and the detected object, the distance measurements were not always fully accurate. In some cases, the ultrasonic sensors provided more reliable distance data, and the robot would use this sensor data for distance calculation rather than relying solely on the camera's measurement. This ensured more precise operation of the robotic arm when handling detected objects.

Navigation Data:

The robot's navigation data showed that its path adjustments depended on the dimensions of the cleaning area and the number of obstacles present. When obstacles were detected, the robot was able to efficiently modify its route, maintaining the Zigzag pattern or reorienting itself as needed.

Cleaning Efficiency:

The robot was tested on two types of floors: tile and wood. Both surfaces were cleaned effectively by the vacuum motor and front/main brushes. However, the mopping function yielded better results on wood floors than on tile. The types of debris tested included:

- **Small plastic pieces and wood remains:** Successfully cleaned, with no issues.
- **Small screws:** Some screws got stuck in the main brush teeth. This problem was mitigated by providing a small, handy tool to clean the brush and remove stuck items.

Statistical Treatment

To ensure the reliability of the sensor data, particularly the ultrasonic sensors, multiple readings were taken during each test, and their mean values were calculated. This approach helped to smooth out any potential anomalies in sensor readings, thereby reducing the likelihood of incorrect movements due to faulty data.

The camera’s object detection also relied on statistical algorithms to estimate the confidence level for each detection (e.g., "85% bottle"). This statistical output enabled more reliable operation of the robotic arm.

Tables

Table 1: Object Detection Accuracy

Test	Object Type	Confidence (%)	Detection Result
1	Plastic Bottle	95	Detected
2	Aluminum Bottle	85	Detected
3	Plastic Bottle	96	Detected
4	Aluminum Bottle	87	Detected

Table 2: Surface Cleaning Performance

Surface Type	Cleaning Effectiveness (Suction and Brush)	Mopping Effectiveness
Tile	Good	Fair
Wood	Good	Excellent

Final Product images:

The following images showcase the completed *CleanItAll* robot, highlighting its design, and overall appearance. These visuals clearly represent the robot's final form after assembly, illustrating the robotic arm.

Figure 13: overview of the final product

Figure 14: final product with the arm

Figure 15: cleaning components under the robot

Key Findings

Based on the tests conducted, the following key findings were observed:

1. **Sensor Accuracy:** The ultrasonic and IR sensors performed reliably, detecting obstacles and edges with high accuracy. There were no instances of false readings or missed detections during the tests, which indicates that the sensor setup is robust for general navigation tasks.
2. **Object Detection Performance:** The camera's object detection system, particularly for bottles, was highly effective, providing 100% detection accuracy during all trials. The confidence levels provided by the camera for detected objects ranged from 85% to 93%, which is within acceptable limits for such a system.
3. **Cleaning Efficiency:** The robot's cleaning system was generally effective on both tile and wood surfaces. The vacuum and brushes worked well on both surfaces, but mopping was more efficient on wood floors. Small debris, such as plastic pieces and wood remains, were cleaned without issue. The only challenge encountered was with small screws, which occasionally became stuck in the main brush.
4. **Navigation:** The robot's Zigzag movement mode, guided by the ultrasonic sensors, was reliable in detecting obstacles and adjusting its path accordingly. This ensured that the robot could navigate spaces effectively, even in the presence of numerous obstacles.
5. **Comparison with Design Expectations:** The robot's actual performance closely matched the expectations set during the design phase. Although some more advanced features were initially planned, time constraints limited their inclusion. Despite this, the current system performs well and fulfills its primary objectives.

Error and Uncertainty

Although the robot performed well during testing, a few sources of potential error were identified:

1. **Pin Connections:** One of the primary concerns is the possibility of pins becoming disconnected from the Arduino. While measures were taken to secure the connections, this remains a potential point

of failure. A pin disconnection could lead to inaccurate sensor readings or malfunctions in other components.

2. **Sensor Readings:** Another possible source of error is the reliability of sensor data. Although the readings were accurate during testing, there is always the risk of occasional incorrect readings due to external interference, environmental conditions, or hardware malfunctions. A failed sensor reading could significantly impact the robot's behavior, especially in navigation and object detection tasks.

Discussion:

Problem Resolution

The primary objective of the CleanItAll robot was to develop an autonomous cleaning system that could navigate various floor surfaces, detect objects, and clean efficiently. The project successfully addressed these objectives, particularly in navigation, obstacle detection, and the ability to clean different types of floors. The robot's main mode of movement, a Zigzag pattern guided by ultrasonic sensors, worked effectively across all tests, and the object detection system based on the OAK-D camera provided accurate identification of bottles. Additionally, the cleaning mechanism, which involved brushes, a vacuum motor, and mops, proved capable of handling multiple types of debris.

However, certain limitations were identified, particularly with the robot's sucker system, which initially struggled with weaker motors. This was resolved by sourcing a more powerful motor, ensuring that the robot could effectively handle dirt and debris. The IR sensor, which served as an anti-fall mechanism, performed consistently and prevented the robot from falling down stairs, achieving one of the key safety objectives. Despite some constraints and challenges, the robot largely fulfilled the original design goals.

Key Contributions

CleanItAll made several noteworthy contributions in the context of autonomous cleaning systems:

1. **Innovative Cleaning System:** The combination of side brushes, a central brush, a vacuum motor, and dual mops allowed the robot to handle a variety of debris, including small plastic pieces, wood remains, and screws. This multifunctional cleaning approach demonstrates a significant advancement over simpler cleaning robots that only vacuum.
2. **Accurate Object Detection and Arm Handling:** The integration of the OAK-D camera for object detection, coupled with a robotic arm, allowed the robot to identify and remove larger objects like bottles. This feature is a key differentiator from many commercially available cleaning robots, which typically lack this capability.
3. **Custom Hardware Solutions:** The use of 3D-printed components, such as the gear for the back mops, illustrates a unique approach to solving mechanical challenges while maintaining a budget-conscious mindset.

These contributions highlight the innovative aspects of the project and its potential for real-world applications in both residential and industrial environments.

Comparison to Current Knowledge

When compared to existing cleaning robots on the market, CleanItAll offers several enhancements. Many commercial robots, such as those from iRobot or Xiaomi, focus primarily on vacuuming and mopping. CleanItAll's inclusion of an object recognition system and a robotic arm for removing larger items sets it apart. The use of the OAK-D camera, capable of both identifying objects and providing distance measurements, adds a layer of sophistication not typically seen in consumer-grade robots. While these advanced features are valuable, the limitations of the camera's distance accuracy show that there is still room for improvement, particularly in complex object handling tasks.

In terms of navigation, CleanItAll's Zigzag pattern, controlled by ultrasonic sensors, is similar to existing systems. However, the use of multiple ultrasonic sensors for precise obstacle detection, along with an anti-fall IR sensor, provides additional safety and efficiency. The project aligns well with current robotics research, which emphasizes multi-sensor integration for autonomous systems.

Limitations

Several limitations were encountered during the project, and these should be considered when evaluating the overall performance of the robot:

1. **Time Constraints:** The project faced time limitations, which prevented the inclusion of additional planned features. More advanced functionalities, such as enhanced object recognition or more complex cleaning algorithms, had to be excluded due to these constraints.
2. **Camera Distance Accuracy:** Although the OAK-D camera provided reliable object detection, the distance measurements were not always fully accurate. In certain cases, the ultrasonic sensors provided more reliable distance information, necessitating a combination of sensor data for effective robot operation.
3. **Budget Constraints:** The limited budget affected some design decisions, particularly in relation to the choice of sensors and motors. For example, the LDR sensor could not be included due to its cost and lack of availability. The overall design had to be adjusted to work within these constraints, which limited the ability to add more advanced features.

Implications of Results

The successful development of CleanItAll demonstrates the feasibility of combining multiple cleaning mechanisms, object detection, and navigation systems in a single robotic platform. This project’s results have broader implications for future cleaning robots, particularly in improving the automation of cleaning tasks in environments with a variety of debris types and objects. The integration of a robotic arm with a vision system offers promising potential for future applications in both commercial cleaning robots and other autonomous systems that require object manipulation.

Moreover, the use of ultrasonic sensors alongside a camera for both navigation and object handling suggests a multi-sensor approach is essential for autonomous systems, particularly in environments where a single sensor may not provide all necessary data. This multi-sensor integration can be applied to other fields such as autonomous vehicles, industrial robots, and personal assistance robots.

Suggestions for Future Work

1. **Movement Code Enhancement:** Improving the movement code could further enhance the robot's reliability and navigation. By integrating an area-scanning function at the start of the cleaning cycle, the robot could map out its environment and identify optimal paths. This would make the movement more reliable and help the robot avoid obstacles more efficiently, reducing the chance of collisions or missed spots.
2. **Extended Cleaning Algorithms:** Future versions of the robot could include more advanced cleaning algorithms, allowing it to better optimize its cleaning path based on room dimensions or areas with higher dirt concentration. This could lead to more efficient cleaning and reduced energy consumption.
3. **Advanced Object Recognition:** While the current system detects bottles effectively, expanding the object recognition system to handle a wider variety of items could increase the robot's usefulness. This could include recognizing household items, toys, or even identifying and sorting recyclable materials.
4. **Longer Testing Periods:** Additional testing over extended periods would provide a better understanding of the robot's long-term performance and reliability, as well as identify any potential wear and tear issues that might arise from continuous operation.
5. **Enhanced Camera Accuracy:** Future iterations of the robot could focus on improving the accuracy of the camera's distance measurements. This could be achieved by incorporating advanced algorithms for depth sensing or using additional distance sensors to complement the camera.

Conclusion and Recommendations:

The development of the CleanItAll robot has been an immensely valuable and enriching journey, both technically and personally. The process of designing, building, and testing an autonomous cleaning robot provided us with hands-on experience in integrating mechanical, electronic, and software systems into a single, functional unit. This project not only expanded our knowledge but also offered practical problem-solving opportunities that will have a lasting effect on our professional and personal lives. The lessons learned from this journey will continue to influence our work and thinking for years to come.

Summary of Results

The primary objective of this project was to develop a multifunctional cleaning robot capable of autonomous navigation, object detection, and effective cleaning across multiple surfaces. The CleanItAll robot successfully achieved these objectives:

- **Navigation and Obstacle Detection:** The robot's Zigzag movement, guided by ultrasonic sensors, allowed it to navigate around obstacles with high accuracy. No false readings were detected during the testing, and the robot was able to adjust its path effectively.
- **Object Detection and Removal:** The OAK-D camera provided reliable object detection with 100% accuracy, successfully identifying bottles and guiding the robotic arm to remove them from the cleaning area.
- **Cleaning Efficiency:** The robot performed well on both tile and wood floors, effectively cleaning small debris such as plastic, wood remains, and screws. However, some screws became stuck in the main brush, a minor issue that was addressed with a handy tool for manual removal.
- **Safety Features:** The robot's anti-fall IR sensor worked perfectly, preventing the robot from falling off stairs or elevated surfaces.

These outcomes demonstrate that CleanItAll met its design goals and performed effectively in real-world testing scenarios.

Recommendations for Improvement

Although the project was successful, several areas for improvement were identified to enhance the robot's overall performance and efficiency:

1. **Movement Code Enhancement:** Improving the movement algorithm by integrating an area-scanning function would allow the robot to map out its surroundings and navigate more efficiently. This would help the robot optimize its cleaning paths, particularly in cluttered or irregular spaces.
2. **Longer Testing Periods:** Conducting extended testing under different conditions would provide more data on the robot's long-term performance and reliability. This would help to identify any potential issues related to continuous operation.
3. **Enhancing Camera Accuracy:** While the OAK-D camera provided reliable object detection, the distance measurement could be further improved. Incorporating additional depth-sensing technology or fine-tuning the existing algorithms could help make object handling more precise.

These recommendations are cost-effective and feasible, with the potential to significantly enhance the robot's capabilities without adding excessive complexity.

Conclusions and Learnings

Throughout the development of CleanItAll, we gained an in-depth understanding of the challenges involved in integrating multiple systems—mechanical, electronic, and software—into a cohesive and functional robotic unit. The key conclusions we have drawn from this experience include:

- **Multisensor Integration is Crucial:** The successful combination of ultrasonic sensors, an IR sensor, and a camera system was essential to the robot's reliable performance. Each sensor had its strengths and compensated for the limitations of the others, demonstrating the importance of a multi-sensor approach in autonomous systems.
- **Mechanical Design Matters:** The physical design of the cleaning mechanisms (brushes, mops, vacuum motor) had a significant impact on the robot's effectiveness. Attention to detail in these areas is crucial for ensuring long-term performance and minimizing the need for manual maintenance.

- **Iterative Design is Key:** Many aspects of the project, from selecting motors to adjusting sensor thresholds, required iterative testing and refinement. This process reinforced the importance of flexibility and adaptability in design thinking.
- **Importance of Safety Features:** The integration of safety measures, such as the anti-fall IR sensor and emergency shutoff, was critical in ensuring that the robot could operate safely in a variety of environments.

This project has been an invaluable learning experience, showing us the complexities of robotics development while also emphasizing the need for thorough testing, thoughtful design, and ongoing improvement.

Future Work and Open Problems

While CleanItAll achieved its primary goals, there are several directions for future work and unresolved challenges that remain:

- **Expanded Object Recognition:** Future versions of the robot could include more advanced object recognition capabilities, allowing it to identify a wider range of objects (beyond bottles) and make more intelligent decisions regarding their handling.
- **Improved Power Efficiency:** Exploring ways to optimize the robot's power consumption could extend battery life, making it more efficient for larger cleaning areas or extended operation periods.
- **Enhanced Path Planning Algorithms:** While the Zigzag movement was effective, future development could include more advanced path planning algorithms that allow the robot to dynamically adapt to its surroundings and optimize its cleaning path further.
- **Integration with Smart Home Systems:** A potential future direction could be the integration of the robot with smart home systems, allowing it to communicate with other devices and systems in the home for a more holistic approach to automation.

These future improvements would not only enhance the functionality of CleanItAll but could also contribute to broader developments in the field of autonomous robots.

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