

DuoSanBot: An Intelligent Dual-Mode Sanitization Robot with Autonomous Navigation

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Abstract - DuoSanBot is an intelligent dual-mode sanitization robot developed to automate the disinfection process in indoor environments. The robot integrates two sanitization mechanisms—UV-C light sterilization for surface-level microbial elimination and liquid disinfectant spraying for broader area coverage. This dual approach enhances overall hygiene efficiency while reducing human exposure to contaminated spaces. To achieve autonomous navigation, the robot is powered by ROS 2, utilizing SLAM, LiDAR-based mapping, IMU feedback, and ultrasonic obstacle detection. These components enable DuoSanBot to create an accurate map of its surroundings, plan optimal cleaning routes, and safely navigate dynamic environments. The system includes a microcontroller-based control unit, motor driver module, and real-time monitoring interface for efficient operation and user supervision. The primary objective of this project is to design a reliable, safe, and energy-efficient sanitization system suitable for hospitals, offices, laboratories, and public facilities. DuoSanBot significantly reduces manual labour, improves disinfection consistency, and ensures faster sanitization cycles—making it highly beneficial in maintaining hygiene standards, especially during pandemic-like situations.

Keywords— ROS 2, SLAM, LiDAR mapping, UV-C sterilization, Autonomous navigation, Embedded control systems.

1. Introduction

In recent years, the demand for efficient and reliable sanitization systems has increased significantly across hospitals, offices, laboratories, educational institutions, and public facilities. Conventional sanitization methods rely heavily on manual labour, often resulting in inconsistent coverage, prolonged cleaning cycles, and increased exposure of personnel to harmful pathogens. To address these limitations, this work presents DuoSanBot, an intelligent autonomous robot designed to perform dual-mode sanitization through the integration of UV-C irradiation for microbial inactivation and a liquid disinfectant spraying mechanism for enhanced area coverage. The system leverages advanced robotics technologies, including ROS 2-based architecture, LiDAR-assisted SLAM, and multi-sensor fusion, enabling autonomous navigation in complex indoor environments. Equipped with LiDAR, IMU, ultrasonic sensors, and encoder feedback, the robot is capable of real-time mapping, obstacle avoidance, and

optimized path planning. A microcontroller-based control framework, combined with a real-time monitoring interface, ensures reliable operation and user interaction. By reducing manual effort, minimizing infection risks, and maintaining consistent hygiene standards, DuoSanBot offers a scalable and efficient solution aligned with the growing requirements of modern sanitization systems.

A. Necessity

The necessity of this project arises from the increasing need for efficient, safe, and consistent sanitization in indoor environments. Conventional manual cleaning methods are time-consuming, labour-intensive, and often result in uneven disinfection coverage, thereby increasing the risk of pathogen transmission. An autonomous sanitization system can significantly reduce human exposure, improve reliability, and ensure uniform hygiene standards across different operational spaces.

B. Objective

The primary objective of this work is to design and develop an autonomous dual-mode sanitization robot capable of effective indoor navigation and disinfection. The system aims to integrate UV-C irradiation and liquid disinfectant spraying mechanisms, along with sensor-based perception and ROS 2-based control, to achieve efficient coverage, obstacle avoidance, and real-time monitoring.

C. Theme

The project is based on the development of an autonomous mobile robotic system for dual-mode sanitization, combining advanced sensing, navigation, and disinfection technologies to enhance operational efficiency, safety, and reliability in indoor hygiene management.

D. Feasibility Study/Market Survey

The growing demand for automated sanitization solutions in healthcare, commercial, and public sectors highlights the feasibility of the proposed system. Existing solutions are often limited by high cost or reliance on a single disinfection technique. DuoSanBot addresses these limitations by offering a cost-effective, scalable solution that integrates dual sanitization modes with autonomous navigation. With the increasing adoption of robotics and smart systems, the project demonstrates strong technical viability and significant potential for real-world implementation.

2. Literature Review

Chen et al., [1] autonomous robotics has rapidly advanced in perception, localization, mapping, and navigation. Their survey categorizes modern navigation algorithms, including RRT and D* variants, and highlights challenges in dynamic environments. Although theoretical in nature, the study provides essential insights for improving DuoSanBot's obstacle avoidance and route optimization capabilities.

Chen et al., [2] a dual-function UV-C and hydrogen peroxide disinfection robot was developed using a Hamilton–Jacobi reachability-based safety filter. This safety mechanism ensures collision-free navigation in complex environments. While the work focuses mainly on the safety filter and controlled experiments, the findings guide the integration of advanced safety layers into DuoSanBot's autonomous navigation system. Hassan et al., [3] a hybrid UV-C and spray-based sanitization robot was proposed, capable of switching modes based on sensor feedback. Although the prototype validates dual-mode operation, it lacks autonomous SLAM-based navigation. The study supports DuoSanBot's dual-modality design and emphasizes the need for a more intelligent autonomous navigation stack.

Yu et al., [4] a ROS- and IoT-enabled disinfection robot was developed for home environments, controlled via a mobile application. The system demonstrates effective ROS implementation but relies heavily on manual operation. This reinforces the importance of ROS integration and motivates DuoSanBot's transition toward fully autonomous decision making.

Al-Dubooni et al., [5] a hybrid continuum-eversion robot was introduced for navigation and decontamination in constrained environments such as nuclear facilities. While unsuitable for wheeled indoor sanitization, its concepts of precision navigation and targeted delivery inspire enhancements to DuoSanBot's movement accuracy in dense obstacle environments.

Bratu et al., [6] the RoboCoV Cleaner utilizes a dual-safety strategy combining PIR sensors and AI-based 360° human detection. Achieving up to 99% detection accuracy, the system ensures immediate UV-C deactivation when humans are detected. Although the study lacks advanced navigation algorithms, it demonstrates essential safety mechanisms that DuoSanBot can integrate alongside SLAM-based path

planning.

Yao et al., [7] a combined UV-C and hydrogen peroxide aerosol system achieved a 92.95% disinfection rate, outperforming single-mode robots. However, the study does not detail navigation or software architecture. DuoSanBot addresses this gap by integrating dual modality sanitation with a ROS 2–based autonomous navigation framework.

Russignaga et al., [8] UV-C autonomous robots significantly reduce microbial loads in real world indoor settings. Due to line-of-sight limitations, UV-C is ineffective in shadowed regions, and airborne disinfection is not addressed. DuoSanBot overcomes these constraints by including a chemical spray mechanism to ensure complete surface and air sanitization.

Perminov et al., [9] developed UltraBot, an autonomous UV-C disinfection robot utilizing SLAM-based navigation and multiple sensors for indoor environments. The system demonstrated significant bacterial reduction and effective obstacle avoidance; however, its reliance on UV-C irradiation introduces limitations such as line-of-sight dependency and reduced effectiveness in shadowed regions. DuoSanBot addresses these limitations by integrating a chemical spray mechanism alongside UV-C, ensuring more comprehensive surface and air sanitization.

Conroy et al., [10] proposed a cost-effective robotic platform for indoor UV-C disinfection with an optimized path planning algorithm to improve coverage and efficiency. While the approach enhances disinfection time and surface coverage, it primarily focuses on UV-based sterilization and lacks detailed consideration of safety mechanisms and multi-modal disinfection. DuoSanBot extends this work by incorporating dual-mode sanitization along with safety-aware design and real-time monitoring for improved reliability and effectiveness. Wang et al., [11] developed a low-cost intelligent disinfection robot based on the STC89C52 microcontroller, incorporating infrared sensors for obstacle avoidance and path tracking. The system was experimentally validated against *Staphylococcus aureus* and mold, achieving over 96% disinfection efficiency. While the design demonstrates cost-effectiveness and reliable basic functionality, it is limited to simple environments and lacks advanced navigation capabilities and multi-mode sanitization. These findings highlight the importance of integrating more sophisticated control systems, dual-mode disinfection (UV-C and spray), and scalable IoT-based

monitoring, which are addressed in the design of DuoSanBot. Patruno et al., [12] developed a vision-based omnidirectional autonomous robot designed for indoor navigation and localization in manufacturing environments. The system integrates stereocameras, laser scanners, and IMU sensors to enable accurate localization, obstacle avoidance, and tag detection. Experimental results demonstrate high precision in navigation and robust performance in dynamic industrial settings. However, the approach is limited to manufacturing applications and lacks disinfection capabilities, while vision-based systems may face challenges under poor lighting conditions. These findings support the integration of vision-based localization with sanitization functionalities, which is further enhanced in DuoSanBot through the inclusion of dual-mode disinfection mechanisms.

Choudhary et al., [13] designed an automated UV-C sterilization robot for disinfection of public spaces using Arduino, ultrasonic sensors, and ESP8266 Wi-Fi for communication. The system incorporates obstacle avoidance and basic autonomous navigation, and was successfully tested in real-world public environments, demonstrating effective UV-C-based disinfection and the feasibility of a low-cost design. However, the approach is limited to UV-C sterilization, lacking adaptive control, multi-mode sanitization, and robust SLAM-based navigation. These limitations highlight the need for hybrid disinfection methods and advanced autonomy, which are addressed in DuoSanBot through the integration of UV-C and spray-based sanitization along with intelligent navigation capabilities.

Wang et al., [14] proposed a UVC surface disinfection robot utilizing a map-based approach with an improved A* algorithm combined with a nearest-neighbor search to generate efficient and collision-free coverage paths. The system operates on a 2D map and is designed to function with low computational resources, making it suitable for edge-based implementations. Experimental validation in a real-world environment demonstrated improved path efficiency, reduced path length, and better coverage compared to traditional A* algorithms. However, the study primarily focuses on path planning optimization and does not address safety mechanisms for human-robot interaction. These findings contribute to efficient navigation design, which is further enhanced in DuoSanBot by integrating advanced safety systems and multi-modal

disinfection capabilities.

Füszl et al., [15] conducted a hospital-based field study to evaluate the effectiveness of a UV-C disinfection robot as a supplement to manual cleaning. The results showed a significant reduction in microbial load on surfaces; however, the system was less effective against resistant pathogens such as *Candida auris* and required frequent operator intervention due to a non-intuitive interface. Additionally, the UV-C approach was limited by its single-mode operation and inability to disinfect shadowed regions. These limitations highlight the need for more comprehensive and user-friendly solutions, which are addressed in DuoSanBot through dual-mode sanitization and improved system autonomy.

Zhao et al., [16] developed a smart sterilization robot that uses chlorine dioxide (ClO_2) spray for disinfection in hospital environments. The system combines IoT-based control, semi-autonomous operation, and gesture recognition, and demonstrated high effectiveness with a 99.8% reduction of *E. coli*. However, the approach focuses solely on chemical disinfection and may be limited by factors such as chemical volatility and the need for controlled environments. It also lacks a detailed safety framework for human interaction. These limitations highlight the need for a more versatile and safer system, which is addressed in DuoSanBot through the integration of both UV-C and spray-based sanitization along with enhanced safety mechanisms.

Sharma et al., [17] presented a simulated autonomous sanitizing robot designed for public spaces such as malls and parks, using an Arduino UNO with ultrasonic and IR sensors for obstacle avoidance and a pump-based liquid spray system for disinfection. The system was validated through simulations in TinkerCAD and SolidWorks, demonstrating effective obstacle avoidance and parallel sanitization in small-scale environments. However, the design is limited to liquid-based disinfection, lacks advanced navigation capabilities such as SLAM, and is not suitable for large-scale deployment. These limitations emphasize the need for improved autonomy and multi-mode sanitization, which are addressed in DuoSanBot through the integration of UV-C disinfection, intelligent navigation, and scalable system design.

Ruan et al., [18] developed an autonomous indoor disinfection robot integrating a hydrogen peroxide atomization system with SLAM-based navigation for effective sanitization in complex

indoor environments. The system demonstrated high efficiency in large-scale disinfection and was validated through practical testing and third-party evaluation. However, it relies solely on chemical-based sanitization, which may require longer application and ventilation times and lacks immediate surface sterilization capabilities. These limitations highlight the need for a hybrid approach, which is addressed in DuoSanBot by combining chemical mist with UV-C disinfection for faster and more comprehensive sanitization.

Zhang et al., [19] identified airborne transmission as a dominant route for the spread of COVID-19, emphasizing the role of aerosols in indoor environments. The study highlights the importance of effective air and surface disinfection, supporting the need for autonomous sanitization systems like DuoSanBot in enclosed spaces.

Ong et al., [20] investigated environmental contamination of SARS-CoV-2 in hospital settings, revealing significant presence of the virus on surfaces and personal protective equipment. The findings reinforce the necessity of automated disinfection systems to reduce human exposure and improve hygiene standards.

Dumas et al., [21] analyzed the health impact of prolonged exposure to chemical disinfectants among healthcare workers, linking it to respiratory issues such as chronic obstructive pulmonary disease. This highlights the need for controlled and optimized disinfection methods, which DuoSanBot addresses through automated and balanced sanitization approaches.

Jayaweera et al., [22] provided a comprehensive review of COVID-19 transmission through droplets and aerosols, highlighting the persistence of pathogens in indoor air. The study underscores the importance of both surface and airborne disinfection, supporting the integration of multi-modal sanitization strategies in systems like DuoSanBot.

Kalinov et al., [23] proposed a CNN-based barcode detection system for optimizing UAV trajectories in autonomous warehouse stocktaking. The study demonstrates efficient vision-based navigation and task optimization, which can support the integration of advanced perception systems in autonomous robots like DuoSanBot.

Karpyshev et al., [24] developed an autonomous mobile robot using CNN and multi-spectral vision for plant disease detection. The system highlights the effectiveness of vision-based sensing and intelligent analysis, which can be extended

to improve perception and environmental understanding in sanitization robots.

Petrovsky et al., [25] presented an autonomous robotics-based system for customer behavior analytics, utilizing sensors and data processing for real-time monitoring. This work demonstrates the potential of integrating analytics and IoT-based monitoring, which can enhance decision-making and system intelligence in DuoSanBot.

Miao et al., [26] proposed a multi-robot cleaning system using map decomposition for efficient coverage in large environments. The approach improves area coverage and task distribution among multiple robots, which can inspire scalable and efficient coverage strategies in autonomous sanitization systems like DuoSanBot.

Buonanno et al., [27] demonstrated that far-UVC light (222 nm) can effectively inactivate airborne human coronaviruses while remaining safe for human exposure. This study highlights the potential of UV-based disinfection for both air and surface sanitization, supporting the integration of UV-C technology in systems like DuoSanBot.

Kitagawa et al., [28] evaluated the effectiveness of 222-nm ultraviolet light in disinfecting SARS-CoV-2 on contaminated surfaces, showing significant reduction in viral presence. The findings reinforce the role of UV-C irradiation as a reliable disinfection method, which can be combined with other techniques for enhanced effectiveness.

Chanprakon et al., [29] developed an ultraviolet sterilization robot for automated disinfection, demonstrating the feasibility of UV-based robotic systems in controlled environments. However, the system is limited to single-mode UV sterilization, highlighting the need for more versatile and hybrid sanitization approaches as implemented in DuoSanBot.

Hayat et al., [30] proposed a reconfigurable pavement sweeping robot capable of adapting its structure for efficient cleaning in uneven environments. Although focused on cleaning rather than disinfection, the concept of reconfigurable design and adaptive coverage can be applied to improve flexibility and efficiency in autonomous sanitization robots like DuoSanBot.

3. Methodology

The development of DuoSanBot follows a systematic methodology involving system design, hardware integration,

software implementation, and experimental validation to achieve autonomous dual-mode sanitization in indoor environments.

1. System Architecture Design

The overall system is divided into two primary layers: a high-level processing unit and a low-level control unit. The Raspberry Pi serves as the main controller responsible for running ROS 2, handling perception, mapping, navigation, and decision-making processes. The ESP32 microcontroller is employed for low-level control tasks, including motor driver interfacing, actuator control (UV module and spray pump), and sensor data acquisition. Communication between the Raspberry Pi and ESP32 is established through serial communication protocols.

2. Hardware Integration

The robotic platform is designed as a differential drive system using DC geared motors with encoder feedback for precise motion control. A 2D LiDAR sensor is integrated for environment perception and mapping, while ultrasonic sensors provide additional proximity-based obstacle detection. An IMU module is utilized for orientation estimation, and the Pi Camera is incorporated for human detection and monitoring. The sanitization system consists of a UV-C light module for surface disinfection and a liquid spray mechanism for broader area coverage. All components are powered through a centralized battery system with regulated voltage outputs.

3. Software Implementation

The software architecture is implemented using ROS 2, following a modular node-based structure. LiDAR data is processed using SLAM algorithms to generate real-time occupancy maps of the environment. The Nav2 stack is utilized for path planning, localization, and autonomous navigation. Sensor fusion techniques combine data from LiDAR, IMU, and encoders to improve localization accuracy. A separate detection node processes camera input for human presence detection, enabling safety control by disabling UV-C operation when required. Communication between nodes is handled using ROS 2 publisher-subscriber mechanisms.

4. Autonomous Navigation and Control

The robot operates in both manual and autonomous modes. In

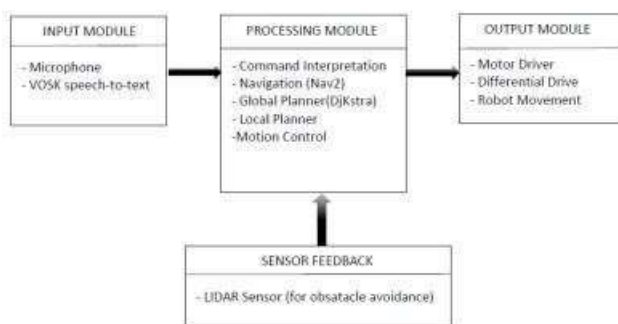
the mapping phase, the robot is manually driven to create an environment map. During autonomous operation, the robot follows a coverage-based path planning strategy to ensure maximum area sanitization. Motor control is achieved using PWM signals from the ESP32, with feedback from encoders enabling closed-loop speed regulation. Obstacle avoidance is handled dynamically using LiDAR and ultrasonic sensor inputs.

5. Dual-Mode Sanitization Mechanism

The sanitization process integrates two complementary methods:

- UV-C irradiation, which provides effective microbial inactivation on exposed surfaces
- Liquid disinfectant spraying, which ensures coverage of shadowed regions and air-contact surfaces

The activation of these mechanisms is controlled based on operational mode and safety conditions. A hardware relay system ensures immediate shutdown of UV-C in the presence of humans.



6. Communication and IoT Integration

A web-based monitoring interface is developed to enable real-time visualization of robot status, including position, sensor data, and sanitization activity. Data is transmitted using lightweight communication protocols, allowing remote control and logging of operations.

7. Experimental Validation

Initial validation begins with comprehensive testing of individual hardware and software components to ensure reliable system functionality. This includes evaluating motor performance in terms of speed control, torque delivery, and response under varying loads, as well as verifying the accuracy, range, and consistency of LiDAR scanning for environment perception. Communication between the Raspberry Pi and ESP32 is rigorously tested for latency, packet loss, synchronization, and robustness under continuous operation. Following component-level validation, simulation-based testing is performed using virtual environments to analyze LiDAR data processing, sensor fusion, and navigation algorithms. These simulations help in assessing path planning efficiency, localization accuracy, and system behavior under different environmental conditions before real-world deployment.

Subsequently, controlled experiments are conducted in indoor environments to evaluate higher-level system performance. This includes testing mapping accuracy using SLAM techniques, analyzing obstacle detection and avoidance in dynamic and static scenarios, and measuring navigation efficiency in terms of path tracking and coverage. Additionally, sanitization effectiveness is assessed by examining area coverage, exposure consistency, and operational repeatability to ensure that the robot meets functional and safety requirements.

4. System Development

Here's a general guide to help you understand the key steps and components involved in the system development:

A. Design Calculation

Motor torque calculation

Parameters:

- $m = 5 \text{ kg}$
- $D = 70 \text{ mm} = 0.070 \text{ m}$
- Radius (r) = $D/2 = 0.035 \text{ m}$
- $g = 9.81 \text{ m/s}^2$

2) Calculate Force (Weight):

The force (F) is the product of mass (m) and the acceleration due to gravity (g).

$$F = m \cdot g$$

$$F = 5 \text{ kg} \cdot 9.81 \text{ m/s}^2$$

$$F = 49.05 \text{ N}$$

3) Static Load Torque (T_L):

The static load torque is the force multiplied by the radius (r).

$$T_L = F \cdot r$$

$$T_L = 49.05 \text{ N} \cdot 0.035 \text{ m}$$

$$T_L = 1.71675 \text{ N} \cdot \text{m}$$

4) Required Motor Torque (T_{motor}):

The required motor torque is the static load torque, multiplied by a safety factor (SF), and divided by the efficiency (η).

- Safety Factor (SF) = 1.25
- Efficiency (η) = 0.85

$$T_{\text{motor}} = \frac{T_L \cdot SF}{\eta}$$

$$T_{\text{motor}} = \frac{1.71675 \text{ N} \cdot \text{m} \cdot 1.25}{0.85}$$

$$T_{\text{motor}} = \frac{2.1459375 \text{ N} \cdot \text{m}}{0.85}$$

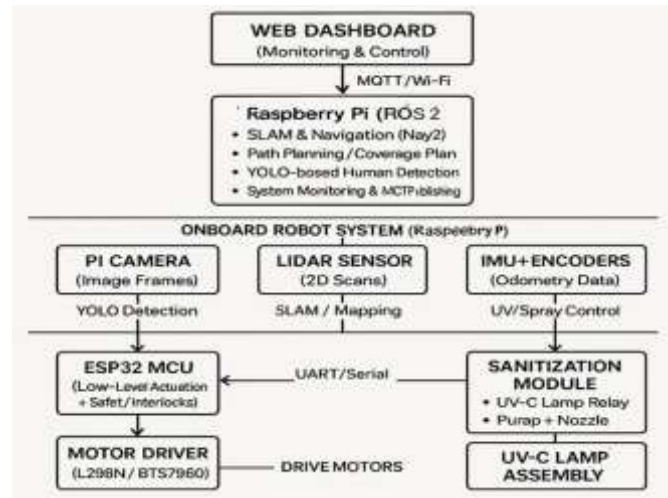
$$T_{\text{motor}} \approx 2.5246 \text{ N} \cdot \text{m}$$

Therefore, the required motor torque is approximately **2.525 N·m**.

B. System Hardware Design on CAD



C. Circuit Design and System Architecture



D. Hardware Components

a) Lidar Sensor

YD LiDAR X2 (360° scanning, 8 m range, 1° resolution): Provides environmental mapping and obstacle detection for SLAM-based navigation in cluttered warehouse settings, mounted centrally for full coverage and integrated via USB with the Raspberry Pi for real-time point cloud processing.



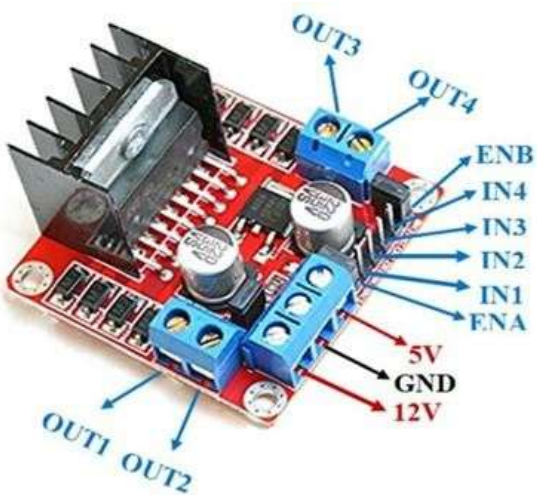
b) Rhino encoder Dc servo Motor

12V DC encoder servo motors (60 RPM, 1.02 N torque): Serve as primary drive motors for differential propulsion, delivering up to 0.4 m/s speeds on the 100 mm wheels while handling inclines up to 5° under 10 kg loads; equipped with Hall-effect encoders for precise odometry ($\pm 8 \text{ mm}$ accuracy).



c) L298N Motor Driver

L298N Motor Driver Modules Manage the motors with and overcurrent protection, enabling accurate torque, direction and speed control of the robot interfaced via pins from the Arduino.



d) Raspberry pi 5

4 GB RAM Model (quad-core ARM Cortex-A76 @ 2.4 GHz): Acts as the high-level brain for ROS2 orchestration, AI path planning, sensor fusion, and WMS integration via Ethernet/Wi-Fi; leverages GPIO for inter-controller communication and Python based edge computing to minimize latency.

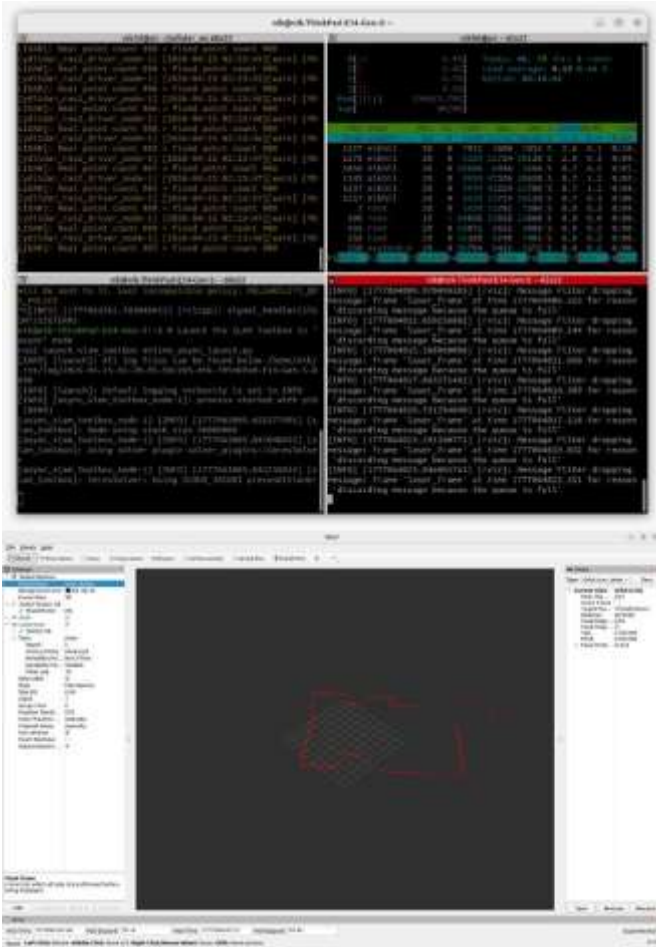


E. ESP32 (Microcontroller)

The ESP32 in DuoSanBot is used to control the spray module, read ultrasonic sensors, and handle safety checks while communicating wirelessly with the main ROS 2 system. It manages fast, low-level tasks so the primary computer can focus on SLAM and navigation, ensuring smooth and reliable robot operation.



5. Result And Discussion



The experimental results demonstrate successful integration of the LiDAR sensor with the ROS2-based SLAM framework. The LiDAR data was continuously published and visualized in RViz, where the robot was able to detect surrounding boundaries and generate a partial map of the indoor environment. The scan data clearly outlines wall structures and obstacles, indicating proper sensor functioning and data acquisition. The SLAM toolbox was successfully launched in asynchronous mode, and the system began processing real-time scan data for mapping and localization. Overall, the system achieved basic environment perception and mapping capability, validating the initial setup.

However, some limitations were observed during execution. RViz displayed frequent message drops with warnings indicating “queue is full,” suggesting a mismatch between data publishing rate and processing capacity. This may be due to high LiDAR frequency, limited computational resources, or suboptimal QoS settings. Additionally, the generated map appears sparse and incomplete, indicating that further tuning of SLAM parameters, sensor configuration, and system

synchronization is required. Addressing these issues—such as reducing scan rate, optimizing QoS policies, or improving hardware performance—can significantly enhance mapping accuracy and system stability in future implementations.

6. Future Scope

The system already performs indoor sanitization and movement effectively, but there is still strong potential to make it more intelligent, faster and better suited for real world use. One important improvement could be adding artificial intelligence to make the robot smarter. For example, the robot could learn from its surroundings and decide the best cleaning path on its own instead of following fixed instructions. This would help the robot work faster and more efficiently in busy places like hospitals, offices, and public buildings.

The system can also be expanded to support remote monitoring using cloud technology. This means users could check the robot’s status, location, and performance from anywhere using a mobile phone or computer. In large buildings, multiple robots could be used together as a team. These robots could communicate with each other and divide the work, which would save time and improve cleaning efficiency.

Finally, improvements in hardware components, such as better sensors, faster processors, and more efficient motors, can make the system more reliable, safer, and suitable for real-world commercial use.

7. Conclusion

This project presents an intelligent autonomous robot designed to perform sanitization tasks in indoor environment. The system combines navigation, obstacle detection, and dual sanitization methods to create a practical and effective solution for maintaining hygiene.

The robot is capable of moving independently, avoiding obstacles, and performing cleaning operations with minimal human involvement. By using modern technologies such as sensors, communication modules, and automated control, the system ensures reliable performance and safe operation.

Overall, the developed system demonstrates a useful and scalable approach to automated sanitization. With further improvements and real-world deployment, this technology has

strong potential to support healthcare facilities, offices, educational institutions, and public spaces in maintaining better hygiene and safety standards.

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