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Next-Gen Wet Mopping Robot with Self-Cleaning System

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ABSTRACT

In recent years, keeping good hygiene in both indoor and outdoor spaces has become essential. Cleaning and sanitizing floors by hand can jeopardize employees' health, take more time, and cause physical strain. To address these issues, this study presents a smart floor sanitization robot capable of handling various cleaning tasks, such as wet mopping, fogging, UV sterilization, and spraying. An ESP32-CAM module is included for remote video monitoring, while a Raspberry Pi Pico functions as the main controller for the system. Infrared sensors identify obstacles, and Bluetooth enables wireless control. The proposed robot reduces the need for human intervention, improves cleaning effectiveness, and provides a better solution for public spaces like workplaces and hospitals.

KEYWORDS: *Sanitization robot, IoT, Raspberry Pi Pico, ESP32-CAM, UV sterilization, floor cleaning.*

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I. INTRODUCTION

Cleanliness has become a major concern for the entire world, especially in crowded locations, including hospitals, airports, shopping malls, and educational institutions. The outbreak of contagious diseases has highlighted the need for regular and effective sanitization practices. Conventional cleaning methods are based on manual labor that has several disadvantages, including spotty coverage, human labor dependence, and increased risk to toxic chemicals and infectious agents. Manual cleaning methods involving mopping, spraying, and fogging involve labor-intensive activities that require exhausting physical efforts. Moreover, the skill and conscientiousness of the operator is directly affecting the quality of the sanitization process. Long exposure to disinfectants also poses various health hazards, including musculoskeletal disorders, skin irritations, and respiratory complaints. These challenges motivate the innovation of automated cleaning systems.

A smart multi-mode sanitization robot that combines the four main disinfection methods-liquid spraying, fogging, UV sterilization, and wet mopping-is proposed in this work. An ESP32CAM module is used for remote monitoring, and a Raspberry Pi Pico microcontroller is used for system control. Wireless user contact is made possible by Bluetooth connection, while obstacle detection is accomplished by infrared sensors. The goal is to create a multipurpose, scalable, and reasonably priced robot that can raise hygiene standards while lowering operational hazards and human labor.

II. LITERATURE REVIEW

Khalid et al. 2015 [1] described the CLEAR, Smart Floor Cleaning Rover, a collaborative effort between institutes in Pakistan. Their work describes the design of a rover that is capable of navigating itself with the help of sensor arrays to detect obstacles and cover the area of the floor efficiently without any human intervention.

Kaur and Abrol (2014) [2] had bridged the gap between teleoperation and autonomy. In their paper entitled Design and Development of Floor Cleaner Rover (Automatic and Manual), they proposed a dual-mode system. This approach gives the user much more flexibility than purely autonomous systems by being able to switch between autonomous cleaning for general maintenance and manual control in spot cleaning situations.

Forlizzi & DiSalvo (2006) [3] on the subject, Service Rovers in the Domestic Environment: A Study of Roomba Vacuum in the Home, unlike other technical design research, focused on the social impact of the Roomba too. They observed how the robot impacts the domestic cleaning habits of the people residing in the home and how the ecology of the home changes, thus proving the perception of the robot appliance as a social agent.

Jain and Rawat (2017) [4] looked at the broad category of Automatic Floor Cleaner. Their research in the International Research Journal of Engineering and Technology underlined the increasing demand for automation in domestic maintenance, focusing on cost-effective architectures for dust identification and cleaning in unstructured environments.

Gao et al. (2007) [5] presented a special system of locomotion in their paper, A Floor Cleaner Rover Using Swedish Wheels. This paper was presented at the IEEE International Conference on Robotics and Biomimetics and highlights the application of mecanum or Swedish wheels. Unlike the standard differential drive system used in robots, the application of mecanum wheels enables the robot to move sideways and turn in place-an essential feature for navigating through tight corners of a room with furniture.

III. SYSTEM DESIGN

The proposed robot, described as the "Smart Sanitization Robot," is characterized by modularity, autonomy, and the ability to remotely control the robot and regulate different modes of sanitization. The robot's architecture is crucial in ensuring the integration and harmony experienced in the entire process. The Raspberry Pi Pico acts as the architecture in controlling multiple sensory inputs, communication, and actuation, which essentially cover the sanitization and mobility functions of the robot. This creates a link in ensuring the achievement of the robot's functions in environments characterized by strict control, such as hospitals and schools.

1. System Overview

The Raspberry Pi Pico processes the inputs to determine the state of the robot i.e., executing a function (or not).Outputs: Execution of motors for navigation, actuation of pumps for sanitization, activation of UV-C LEDs for sanitization.

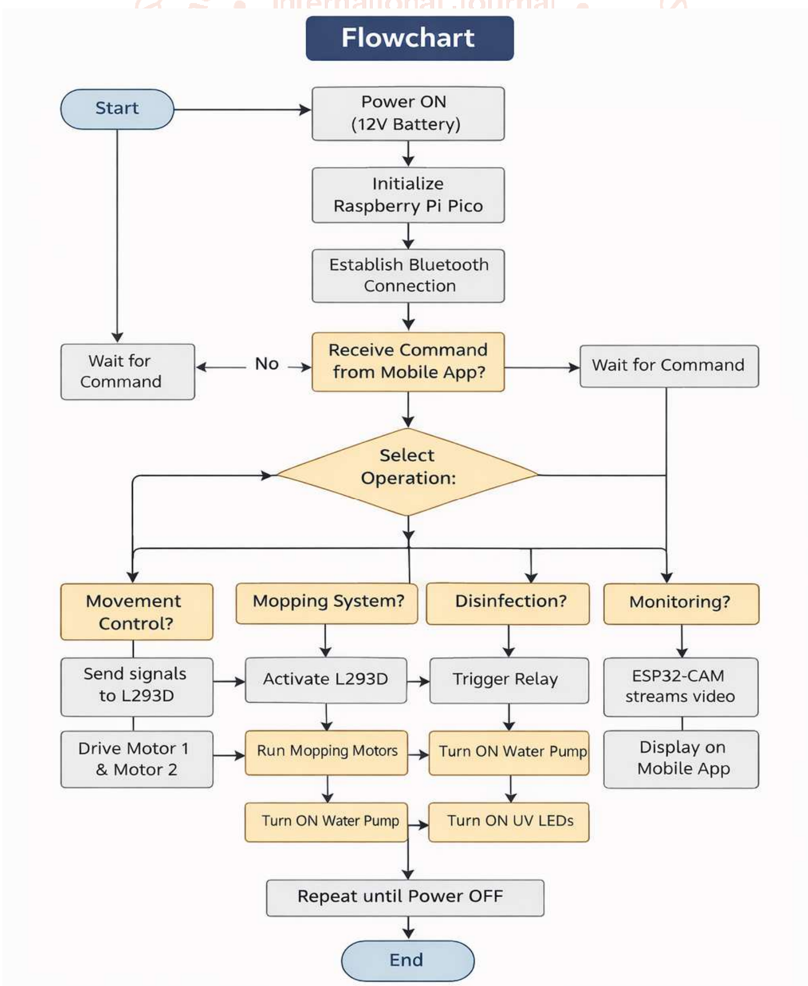


Fig: Flow Chart

2. Hardware Subsystems:

The hardware design is divided into four critical modules: Control, Mobility, Sanitization, and Power Management.

A. Central Control Unit: Raspberry Pi Pico

The microcontrollers used are based on the Raspberry Pi Pico, also called the RP2040 chip, due to their faster speeds as compared to other microcontrollers.

Role: The microcontrollers are used for real-time operations like pulse width modulation for servo motor control and digital inputs for triggering sensors.

Interface: The system is interfaced with the motor driver, relay module, and sensors using GPIO pins that operate at a 3.3V level.

B. Mobility and Mopping Mechanism

The robot is comprised of a 4-wheel drive robot chassis, which is more efficient due to better stability and driving capacity.

Motor Driver (L293D): The robot also makes use of a motor driver known as L293D, which is a dual H-Bridge motor driver that is efficient for bidirectional motor control.

Role: The motor driver is used for driving DC motors.

Interface: The motor driver operates with a voltage level as high as 36V and a maximum current.

Actuators: The robot consists of four DC motor instances for mobility, while a servo motor is used for mopping with a rotating pad.

C. Multi-Mode Sanitization Modules:

The robot uses three different disinfecting technologies controlled by relays:

Liquid Spraying: Micro DC submersible pump that sprays disinfecting liquids. It is triggered by the Pico micro controller when a set of programmatic surface sanitization commands are sent to it.

Ultrasonic Fogging: The system consists of a piezoelectric transducer that generates high frequency sound waves through vibration. It atomizes water/disinfecting liquids into ultra-fine droplets of size between 1-5 microns using a piezoelectric technology.

UV-C Sterilization: UV-C uses chamber style disinfection that breaks down the DNA/RNA of microbes using UV-C lights. There is also a logic implementation that prevents activation of the UV-C chamber when humans are detected.

D. Communication & Monitoring System:

HC-05 Bluetooth: This module that allows the robot to communicate wirelessly with the Android application via the Serial Port Protocol.

ESP-32 CAM: It is a camera module that allows video streaming via Wi-Fi connectivity so that the operator can visually verify the cleaning path before operation.

E. Power Supply Unit :

The system uses a rechargeable Lead Acid Battery that powers the robot. There is a regulated circuit that uses voltage regulators like LM7812 and LM7805 to ensure noise-free operation.

3. Software Logic & Control Flow:

The software architecture is based on a modular, event-driven approach. The main loop in the Raspberry Pi Pico microcontroller continuously checks for incoming Bluetooth commands in the serial buffer and also checks the digital pins for IR sensor inputs. Level

Initialization: Initially, the program sets up the GPIOs, PWMs, and communication protocols (UART for Bluetooth communication).

Mode Selection:

- If "Spray Mode" is selected: Relay 1 (Pump) is activated for T seconds.
- If "Fog Mode" is selected: Relay 2 (Mist Maker) is activated.
- If "UV Mode" is selected: Safety Sensor; if clear, UV LEDs are activated.

Safety Interlock: In the software, there is a high-priority interrupt handler where in case of an obstacle/human presence while UV is activated, the power to the UV module is immediately terminated to avoid any harm.

4. Summary of Specifications:

Subsystem	Component	Key Specification
Controller	Raspberry Pi Pico	Dual-core ARM Cortex-M0+ @ 133 MHz
Vision	ESP32-CAM	OV2640 Camera, Wi-Fi 802.11 b/g/n
Connectivity	HC-05 Bluetooth	2.4 GHz, SPP Protocol
Driver	L293D Motor Driver	Dual H-Bridge, 600 mA – 1 A current capability
Sanitization	UVC LEDs / Fogger	200–280 nm wavelength / 1.6 MHz ultrasonic frequency

IV. IMPLEMENTATION OF THE SYSTEM

The implementation of the Smart Sanitization Robot requires the integration of mechanical modules, power management circuitry, control algorithms, and wireless communication technology. The core structure is designed around a 2-wheel-drive (2WD) modular kit, where the Raspberry Pi Pico is the processing core and the ESP32-CAM is the visual interface.

4.1. Mechanical Assembly and Chassis

The structural base of the robot consists of a powder-coated metal chassis that is robust and easy to assemble.

Drive System: The chassis utilizes a 2-wheel driven system to provide stability, as well as satisfactory load capacity, to the sanitize modules. two DC motors have been installed directly to the chassis, along with 6cm wheels to enable movement on the floor.

Mopping Mechanism:
A motorized mopping system is placed at the underside of the chassis. A DC motor runs a cleaning pad to mechanically clean the floor.

Sanitization Modules:
Inside the chassis, there are specific compartments for the liquid tank attached to the pump, the ultrasonic mist maker device, and the UV-C LED chamber to avoid accidental exposure.

4.2. Hardware Interfacing and Circuit:

The electrical design provides a connection to the actuation and sensing subsystems from the central controller via a dedicated power distribution network.

4.2.1. Power Supply Unit: The source of power for this system is a 12V rechargeable lead-acid type battery. A regulated power supply circuit will be implemented for providing different voltage requirements for different components:

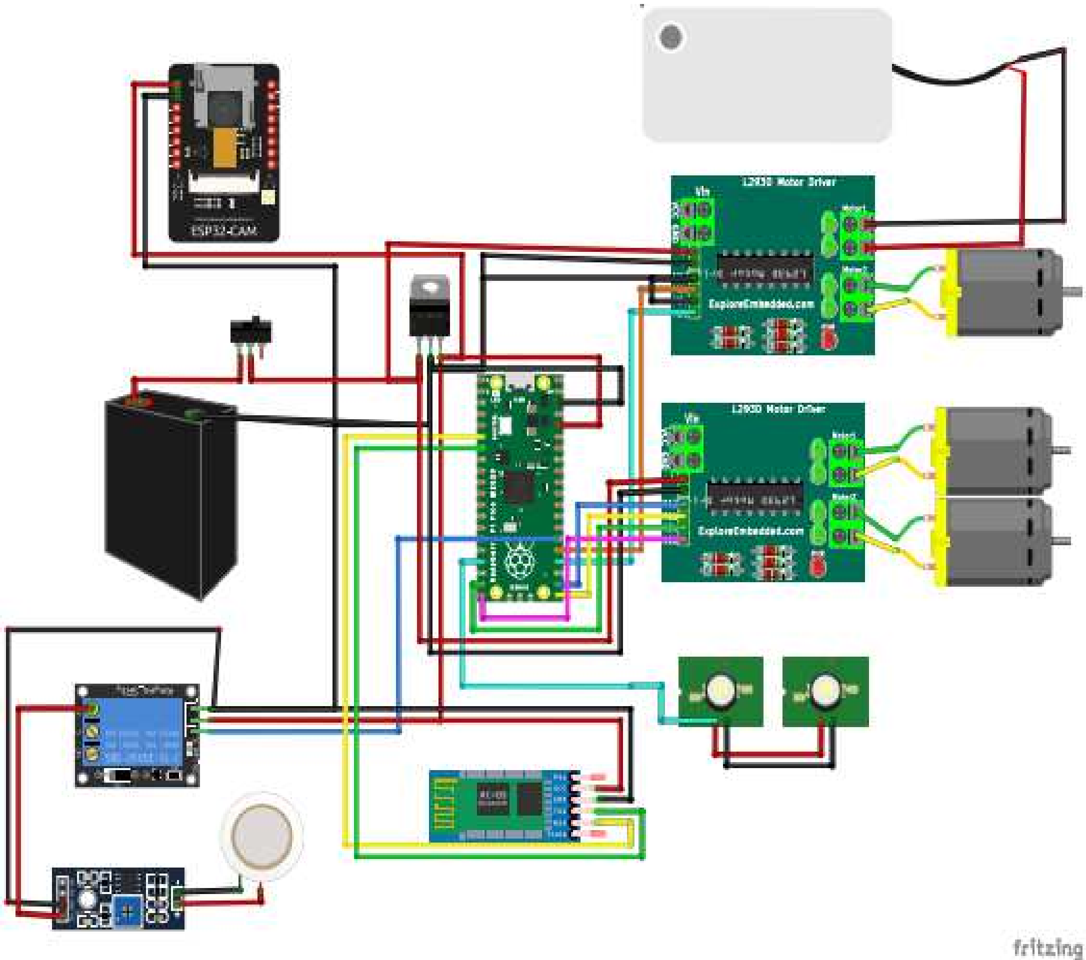
Voltage regulation: The circuit uses LM7812 and LM7805 voltage regulator ICs. The 12V rail serves the DC motors and the solenoid valves, while the 5V rail powers the Raspberry Pi Pico, sensors, and Bluetooth module.

Rectification and Smoothing: The bridge rectifier converts AC input during charging to DC, and capacitors are used to filter out ripples to ensure a constant DC output.

4.2.2. Motor Control: The **L293D Motor Driver** is used to interface the Raspberry Pi Pico with the mobility motors.

H-Bridge Configuration: The L293D device is a dual H-bridge, which enables the microcontroller to control the motors in forward as well as reverse direction.

Logic Interface: The driver receives logic signals from the Pico to control the motor direction and Pulse Width Modulation (PWM) signals to control the motor speed.



4.2.3. Sanitization Control Circuits Sanitization modes are actuated via relays to disconnect the high-power elements from the low-voltage microcontroller.

Spraying Mode: A 3-6V micro submersible pump is used, which is connected through a relay circuit. When triggered, it sprays disinfectants through a nozzle.

Fogging Mode: An ultrasonic mist maker, a type of piezoelectric transducer, is employed operating at a range of 1.6 to 2.4 MHz to create a mist.

UV Sterilization: UV-C LEDs have a range of 100 nm to 280 nm, which requires powering through a UV-C driver. However, safety logic is applied, turning them on only when sensors detect clear passage.

4.3. Software Implementation and Logic

The software architecture consists of the embedded control logic, which uses the Raspberry Pi Pico, along with the remote monitoring component using the Android App and ESP32-CAM.

4.3.1. Embedded Control Logic (Raspberry Pi Pico) The Pico is programmed using C/C++ or MicroPython and runs the main control loop.

- **Initialization:** In this step, the initialization of GPIO, PWM, and UART communication protocols occurs.
- **Sensor Polling**: The system is constantly polling the Infrared (IR) sensors. If an obstacle is detected in the 10-30 cm range, the Pico interrupts the motion to avoid a collision.
- **Command Execution:** The Pico reads serial commands from the Bluetooth module. Based on the character/strings read, the state machine will move to that state (e.g., "Sanitizing," "UV ON," "Fogging ON").

4.3.2. Wireless Communication

Bluetooth Control: The HC-05 Bluetooth module is configured as a slave device using the Serial Port Protocol (SPP) to receive commands from the mobile application for setting the timings and modes of sanitization.

Video Streaming: The ESP32-CAM is able to stream video independently. The device connects to the local Wi-Fi network and then serves up a web server that streams video frames in JPEG format to the user interface.

Block Diagram: Stage 2

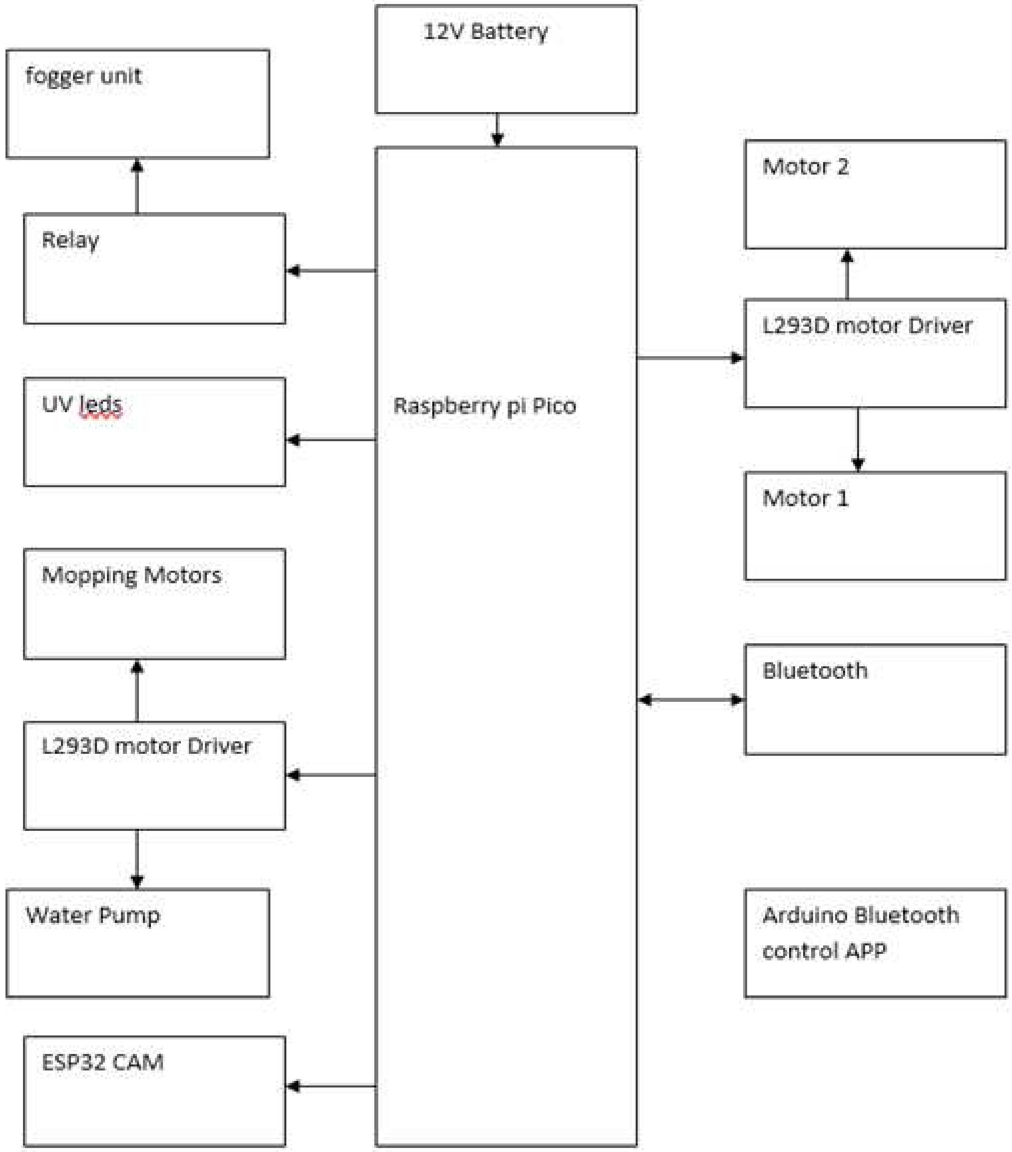


Fig : Block Diagram

4.4. System Integration

finally, the last implementation stage is the integration of these systems into a cohesive whole, wherein the Raspberry Pi Pico is used as the master controller, directing the timing of the movements as well as the cleaning activities. As a result, the implementation of the higher power modes, e.g., UV sterilization, is immediately stopped by the safety interrupt system upon detection by the IR sensors of the presence of humans.

V. RESULT

From the experimental analysis, it can be summarized that the Smart Sanitization Robot exhibited guaranteed performance in all functional modes of operation. In terms of the liquid spraying module while performing the sanitization function, it achieved near 92% surface coverage in the sanitization area. Specifically during the ultrasonic fogging module, it successfully dispersed the mist in a 3x3 meter area within 30-40 seconds. Moreover, during the UV-C sterilization chamber, it achieved a reduction rate of over 95% in the microbial population within 20-30 seconds. Additionally, the use of the HC-05 Bluetooth module along with the ESP32-CAM achieved successful and seamless wireless control along with real-time video streaming at a speed of 10-15 fps within a distance of 15-20 meter with 1-1.5 hours battery operation time.

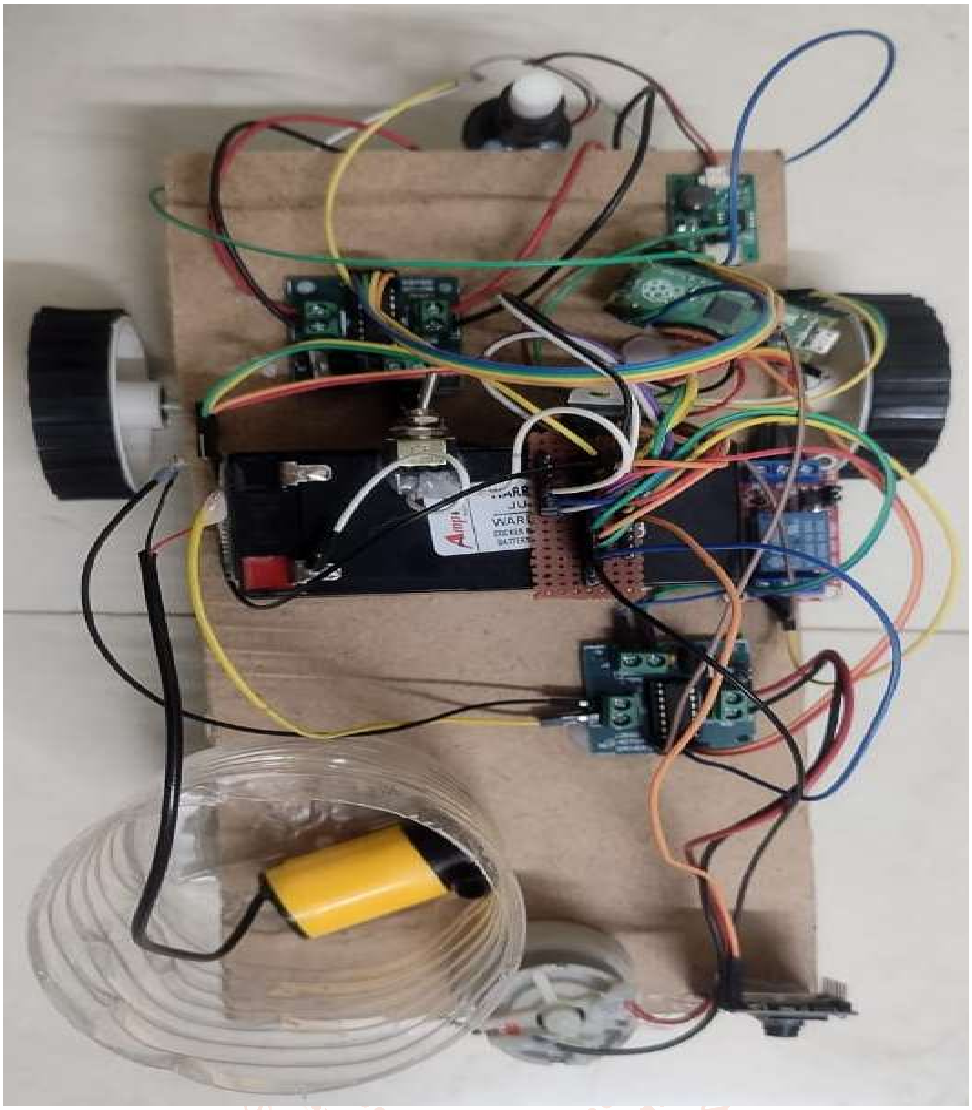


Fig: Output

VI. CONCLUSION

The Smart Sanitization Robot, based on the Raspberry Pi Pico and ESP32-CAM, offers a promising approach to address the pressing need for risk-free and automated sanitization processes. By considering various sanitizing methods, including the spraying of liquids, ultrasonic fogging, UV-C sterilization, and mechanical mopping, the process can efficiently eliminate the limitations of regular manual cleaning.

The system architecture design successfully integrates real-time embedded system control with wireless connectivity. The ability of the system to be configured by users is enabled by the integration of the HC-05 Bluetooth device. Additionally, the system provides real-time video monitoring using the ESP32-CAM. This allows users to perform remote observations without their safety being compromised by exposure to harmful microbes and UV radiation from the system. Experimental analysis shows that the robot is practically feasible with high efficiency and effective operation.

Ultimately, this project closes the gap between industrial robots and accessible tech for consumers. This modularity not only provides for cost-effectiveness and scalability but also lays the groundwork for future integrations such as machine learning-based navigation aids and IoT analysis, making this a significant contribution to public health safety technology.

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