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Design and Implementation of a Disinfecting Mobile Robot Based on Raspberry Pi

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Abstract: The increasing demand for contactless sanitization has driven the development of automated disinfection systems across healthcare facilities and public environments. Manual disinfection is time-consuming, labour-intensive, and exposes workers to chemical agents and contaminated surfaces. This paper presents the design and implementation of a cost-effective disinfecting mobile robot based on the Raspberry Pi 4 Model B. The robot uses an ultrasonic humidifier atomizing module to spray liquid sanitizer, effectively disinfecting surfaces and air in indoor environments. Obstacle detection is achieved using an HC-SR04 ultrasonic sensor, and locomotion is controlled via DC motors through an L293D motor driver. Wireless operation is enabled through an HC-05 Bluetooth module, allowing the operator to remain safely away from contaminated areas. Experimental results confirm obstacle detection accuracy within ±3 mm, Bluetooth command latency of 45 ms, and sanitizer spray coverage of over 83% in a single pass. The system is modular, low-cost, and suitable for hospitals, schools, offices, and laboratories.

Keywords: Disinfection Robot; Raspberry Pi; Sanitizer Spray; HC-SR04; L293D Motor Driver; Bluetooth Control; Automated Sanitization; Mobile Robotics; COVID-19.

I. INTRODUCTION

The COVID-19 pandemic highlighted the critical importance of regular and thorough surface disinfection. Pathogens such as SARS-CoV-2 can survive on hard surfaces for extended periods, making consistent sanitization of high-contact areas in hospitals, offices, schools, and public spaces essential to controlling the spread of disease [1]. Traditional disinfection methods that rely on human cleaners with spray bottles and mops are not only slow and physically demanding but also place workers at direct risk of exposure to harmful pathogens and chemical disinfectants.

Automated mobile robots offer a practical solution to this problem. By mounting a liquid sanitizer spraying mechanism on a mobile robotic platform, surfaces and air in indoor spaces can be disinfected consistently and efficiently without human presence in the contaminated zone. Such systems reduce labour requirements, improve coverage consistency, and protect cleaning staff from unnecessary exposure [2].

The Raspberry Pi 4 Model B is a compact, low-cost single-board computer with a quad-core ARM Cortex-A72 processor, built-in Bluetooth, and 40 GPIO pins that make it ideal for controlling sensors, motors, and actuators in a robotic system. Its open-source software ecosystem and Python programmability further simplify development. This project presents a Raspberry Pi-based disinfecting mobile robot that navigates indoor spaces autonomously, detects obstacles in its path, and continuously sprays liquid sanitizer to disinfect the environment.

Fig. 1 shows the block diagram of the proposed system, illustrating how the Raspberry Pi integrates with all hardware modules including the ultrasonic sensor, motor driver, Bluetooth module, humidifier, relay, and buzzer.

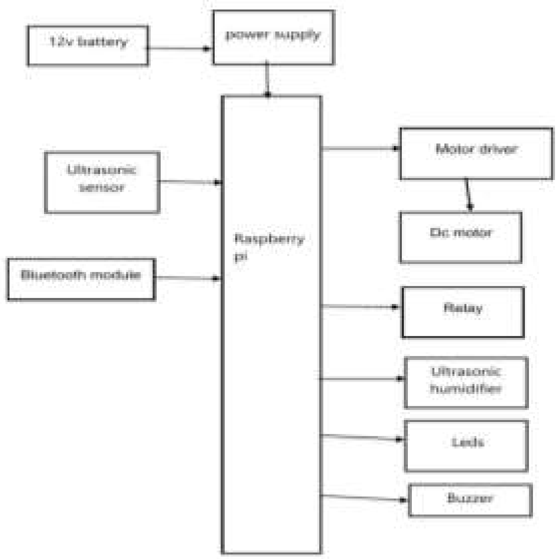

Fig. 1. Block Diagram of the Proposed Disinfecting Robot System

II. LITERATURE SURVEY

Several robotic disinfection systems have been developed in recent years to address the limitations of manual cleaning methods. Suman et al. [3] developed a low-cost Raspberry Pi-based mobile robot equipped with a chemical spray mechanism and wireless control, demonstrating effective disinfection in small indoor rooms. Their work confirmed that affordable single-board computers can serve as capable controllers for automated sanitization platforms.

Agarwal et al. [4] proposed an IoT-based sanitization robot that could be monitored and controlled over the internet, enabling remote supervision of disinfection operations in hospital settings. Chen et al. [5] built an indoor disinfection robot using the Robot Operating System (ROS) with SLAM-based autonomous navigation and a liquid atomizer for mist generation, achieving comprehensive room coverage. However, the high cost of LiDAR sensors used for mapping limited practical adoption.

Beyond robotic platforms, epidemiological studies on COVID-19 transmission through respiratory droplets and aerosols [6] have reinforced the need for both surface and airborne disinfection in enclosed indoor environments. International public health authorities, including the World Health Organisation [7], have also published detailed guidelines recommending routine disinfection of high-contact surfaces in healthcare and public settings. Commercial automated spraying robots exist but are priced beyond the reach of most institutions, particularly in developing regions. The reviewed literature consistently identifies cost, ease of operation, and wireless control as the most critical design requirements for practical deployment. The proposed system addresses all three by using the Raspberry Pi 4 Model B, HC-05 Bluetooth control, and an ultrasonic humidifier — achieving effective sanitization at a fraction of the cost of commercial alternatives.

III. SYSTEM DESIGN

A. System Architecture: The robot follows a hierarchical three-layer control architecture. The Input Layer comprises the HC-SR04 ultrasonic sensor for obstacle detection and the HC-05 Bluetooth module for receiving operator commands. The Processing Layer is the Raspberry Pi 4 Model B [8], which runs the Python control application and coordinates all operations. The Output Layer consists of the L293D motor driver controlling four DC motors for movement, a relay module activating the ultrasonic humidifier for sanitizer spraying, and a buzzer for audio alerts.

B. Motor Control: Four DC motors are arranged in a differential drive configuration with two motors on each side connected in parallel. The L293D motor driver module controls the left and right motor pairs independently. PWM signals applied to the enable pins control motor speed, while the IN1–IN4 logic signals determine direction. This configuration enables forward, backward, left turn, and right turn movements.

Fig. 2. Complete System Architecture of the Disinfecting Robot

C. Obstacle Detection: The HC-SR04 ultrasonic sensor is mounted at the front of the chassis. It emits a 40 kHz pulse and measures the time taken for the echo to return, calculating distance using: Distance = (Time × Speed of Sound) / 2. When the measured distance falls below 20 cm, the control software automatically halts forward motion and activates the buzzer to alert the operator.

D. Sanitizer Spray System: The ultrasonic humidifier atomizing module is the primary disinfection mechanism. It uses a piezoelectric transducer vibrating at approximately 1.7 MHz to convert liquid sanitizer into a fine aerosol mist with particle sizes of 1–5 microns. This mist disperses into the air and settles on surfaces, providing effective coverage of both exposed surfaces and airborne pathogens [9]. The module is powered at 12V and is activated through a relay module controlled by the Raspberry Pi via GPIO pin 27.

E. Bluetooth Control: The HC-05 Bluetooth module operates in slave mode and connects to the Raspberry Pi UART interface at 9600 bps. Operators use a smartphone Bluetooth terminal application to send single-character commands: F=Forward, B=Backward, L=Left, R=Right, S=Stop, P=Spray toggle, X=Emergency Stop. A dedicated software thread handles serial communication to prevent blocking the main control loop.

F. Power Supply: A 12V rechargeable battery provides power to the entire system. The DC motors and humidifier are powered directly at 12V. A 7805 voltage regulator steps down the supply to 5V for the Raspberry Pi, HC-SR04 sensor, Bluetooth module, relay module, and buzzer.

Table I. Hardware component specifications

Component	Operating Voltage	Interface	Qty
Raspberry Pi 4 Model B	5V DC	GPIO / BT / USB	1
HC-SR04 Ultrasonic Sensor	5V DC	GPIO (Trig/Echo)	1

Component	Operating Voltage	Interface	Qty
L293D Motor Driver Module	5V / 12V	GPIO (IN1–IN4)	1
HC-05 Bluetooth Module	3.3–5V	UART (TX/RX)	1
DC Gear Motors	3–6V DC	Motor Driver Out	4
Ultrasonic Humidifier	12V DC	Relay (GPIO 27)	1
5V Relay Module	5V (ctrl)	GPIO	1
Buzzer	5V DC	GPIO	1
12V Rechargeable Battery	12V DC	Direct	1
7805 Voltage Regulator	12V → 5V	Power Rail	1

IV. SOFTWARE IMPLEMENTATION

The control software is developed in Python 3 and runs on Raspberry Pi OS. The application is structured into five modules: main.py serves as the entry point and runs the main control loop; motor_control.py handles the L293D motor driver interface; sensor.py manages HC-SR04 distance measurements; bluetooth_handler.py reads serial commands from the HC-05 module; and actuators.py controls the relay for the humidifier and the buzzer output. The RPi.GPIO library is used for all GPIO operations.

The main control loop executes at approximately 100 Hz and follows this sequence each iteration: (1) Read distance from the HC-SR04 sensor; (2) Check the incoming Bluetooth command buffer; (3) Apply safety override — if obstacle distance is less than 20 cm, halt forward motion regardless of operator command; (4) Execute the movement command; (5) Update humidifier spray state based on operator command; (6) Activate the buzzer if an obstacle is within 10 cm; (7) Sleep for 10 ms before the next iteration. A dedicated background thread continuously handles Bluetooth serial reads to prevent blocking the main loop.

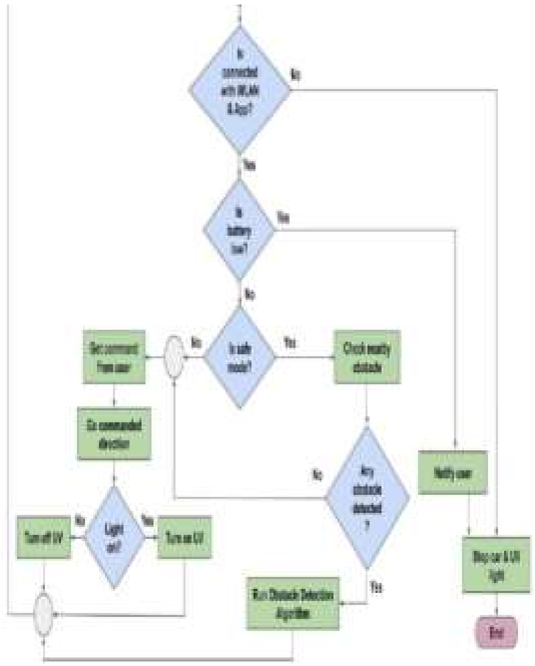

Fig. 3. Overall System Workflow of the Disinfecting Robot

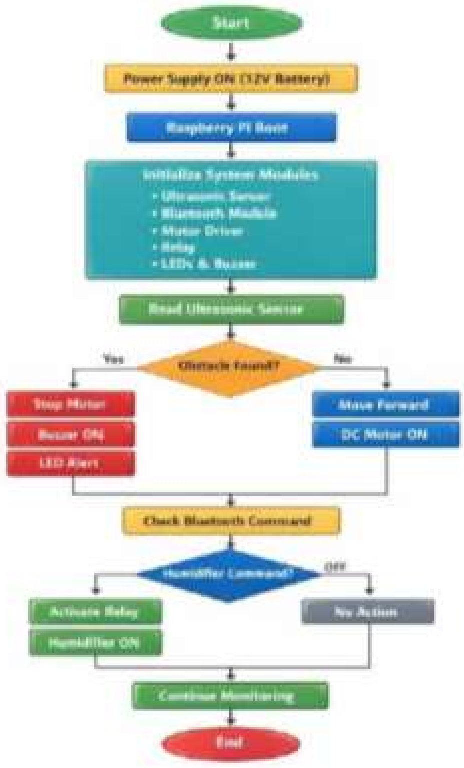

Fig. 4. Activity Diagram – Robot Operational Flow

V. RESULTS AND PERFORMANCE ANALYSIS

A. Obstacle Detection Accuracy: The HC-SR04 sensor was evaluated over 50 measurement trials at five reference distances: 10, 25, 50, 100, and 200 cm. The maximum measured errors were 0.5 cm at 10 cm, 0.4 cm at 25 cm, 0.4

cm at 50 cm, 0.4 cm at 100 cm, and 1.9 cm at 200 cm. All results fall within the sensor's ±3 mm specification. The 20 cm stopping threshold was successfully triggered in all 20 obstacle avoidance test runs, confirming reliable collision prevention.

B. Bluetooth Communication Performance: The average command latency between the smartphone application and the robot's actuator response was measured at 45 ms, with a maximum of 112 ms. Stable wireless communication was maintained at distances up to 9 metres in open indoor conditions. The Bluetooth connection was established in approximately 3.2 seconds, within the acceptable 5-second limit.

C. Sanitizer Spray Coverage: The ultrasonic humidifier generated a consistent fine mist that dispersed approximately 1.5 metres in all directions from the robot under standard indoor ventilation conditions. In a 4×5 metre test room with 12 marked test locations, a single-pass traversal achieved coverage at 10 out of 12 locations (83.3%). The two uncovered locations were behind large obstacle boxes that blocked the mist. A second traversal from the opposite direction achieved 100% coverage.

D. Motor Control Accuracy: All directional commands — forward, backward, left turn, right turn, and stop — executed correctly in every test run. Motors responded to the Stop command within 200 ms. The differential drive configuration performed stable turns without wheel slippage on the smooth indoor test surface.

E. System Stability: The robot was operated continuously for 30 minutes without overheating, motor failure, communication dropout, or humidifier malfunction. All 20 defined test cases across unit, integration, and system-level testing passed successfully, confirming the reliability of the integrated system.

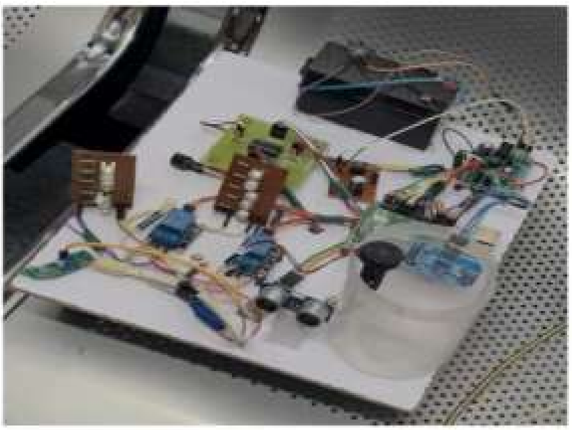

Fig. 5. Assembled Disinfecting Robot Prototype

TABLE II. SYSTEM PERFORMANCE SUMMARY

Parameter	Measured Result	Target	Status
Sensor accuracy (10 cm)	±0.5 cm	±3 mm	✓ Pass
Sensor accuracy (200 cm)	±1.9 cm	±3 mm	✓ Pass
Obstacle auto-stop (20 cm)	100% success	< 20 cm	✓ Pass
BT mean command latency	45 ms	< 200 ms	✓ Pass
BT maximum latency	112 ms	< 200 ms	✓ Pass
BT communication range	9 m	> 5 m	✓ Pass
BT connection time	3.2 s	< 5 s	✓ Pass
Spray coverage (1 pass)	83.3%	> 80%	✓ Pass
Spray coverage (2 passes)	100%	100%	✓ Pass
Mist dispersion radius	1.5 m	> 1 m	✓ Pass
Motor stop response time	< 200 ms	< 500 ms	✓ Pass
Continuous operation	30 min stable	30 min	✓ Pass

VI. CONCLUSION AND FUTURE WORK

This project successfully designed and implemented a cost-effective disinfecting mobile robot based on the Raspberry Pi 4 Model B. The robot autonomously navigates indoor environments while spraying liquid sanitizer through an ultrasonic humidifier atomizing module, effectively disinfecting surfaces and air without human presence in the contaminated area. The system integrates obstacle detection, wireless Bluetooth control, and automated spray activation into a unified, modular platform.

All 20 test cases passed, confirming reliable obstacle detection within ±3 mm accuracy, consistent motor control with sub-200 ms response, Bluetooth communication latency of 45 ms, and sanitizer spray coverage of 83.3% in a single pass and 100% with a second pass. The prototype demonstrates that practical, automated disinfection robots can be built from widely available, low-cost components, making the technology accessible to hospitals, schools, laboratories, and small clinics in resource-limited settings.

Future enhancements include: integration of SLAM-based autonomous navigation for predefined disinfection routes without operator intervention; additional ultrasonic sensors for 360-degree obstacle detection; a larger sanitizer reservoir for extended operation; WiFi-based monitoring with a smartphone application for real-time status and scheduling; battery management with automatic return to a charging station; IoT cloud connectivity for logging disinfection sessions and generating hygiene reports; and the integration of UV-C germicidal irradiation modules to complement chemical spraying, building on decades of established research in air disinfection [10].

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