ChemBot: A Cleaning Robot with Automatic Chemical Detection and Response Mechanisms

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***Abstract*—Automated cleaning and chemical spill detection are essential for maintaining sanitary and safe surroundings, especially in public areas, healthcare facilities, and research facilities. Conventional cleaning robots rarely include specialized chemical sensing or responsive cleaning mechanisms, instead concentrating on removing dust or debris. In this study, we introduce ChemBot, a mobile, autonomous robot created especially to identify spills involving alcohol and carry out localized cleaning tasks. ChemBot has a built-in pump-actuated cleaning system with a mechanical brush, alcohol vapor detection using the MQ-3 gas sensor, differential drive navigation, and real-time ultrasonic obstacle avoidance. Instead of using pricey wheel encoders or LIDAR systems, ChemBot uses a time-based navigation algorithm to ensure cost-effectiveness. In controlled settings that mimicked alcohol spills, extensive experimental validation was conducted. Outperforming several state-of-the-art designs, the results show that ChemBot can detect alcohol concentrations as low as 25 ppm with a cleaning efficiency of 85% and a response time of less than 8 seconds. The advantages of ChemBot's modular, low-cost design are highlighted in this paper along with the hardware-software integration, experimental evaluation, and future development paths for chemical-specific robotic cleaning.**

***Index Terms*—mobile robotics, chemical detection, alcohol sensing, autonomous navigation, ultrasonic sensors, cleaning robot**

I. Introduction

Over the past few decades, autonomous cleaning robots have grown significantly, progressing from basic vacuuming devices to complex systems that can perform specialized cleaning in dangerous settings. Devices like iRobot's Roomba, which mainly targets dust and debris, have shown widespread adoption for cleaning in homes [2]. Through specialized mechanical designs, industrial robots have tackled hazardous spill management and internal pipe cleaning [8].

Despite these developments, the majority of cleaning robots are still surface-focused and cannot perform chemical-specific interventions. Conventional wheel encoders or LIDAR systems may become prohibitively expensive when navigating cluttered indoor environments [9]. Furthermore, most commercially available low-cost platforms lack the capability to identify contaminants such as alcohol spills and start selective cleaning.

Ishida et al. [3] examined the incorporation of volatile compound detection sensors, such as alcohol vapors, in the field of robotic chemical sensing. For navigation in domestic settings, Pandey et al. [1] focused on infrared and ultrasonic technologies. In order to improve navigation in dynamic spaces, Kim et al. [5] talked about behavior-based adaptive control strategies for mobile robots. Specialized cleaning applications have also surfaced, such as the dual-purpose cleaning and mopping robot designed for Indian homes by Adithya et al. [10] and the in-pipe water jet cleaning device developed by Zainal Abidin et al. [8]. Neumann et al. [9] proposed template coverage-based path planning techniques, which Hofner and Schmidt [6] further investigated for thorough area sanitization.

Few systems, nevertheless, integrate targeted cleaning, autonomous navigation, and real-time chemical detection into a single, reasonably priced robotic platform. but are unable to make it economical

We present ChemBot, an integrated, low-cost autonomous cleaning robot with time-calibrated differential drive navigation, ultrasonic obstacle avoidance, MQ-3-based alcohol detection, and a pump-driven cleaning system with mechanical brushing in order to overcome these constraints. ChemBot uses a time-based motion estimation technique to achieve adequate navigation accuracy without the need for expensive sensors.

In Section II, relevant literature is reviewed; in Section III, the hardware and software architecture is explained; in Section IV, the suggested methodology is detailed; in Section V, the experimental setup is explained; and in Section VI, the results and comparisons are discussed. Future improvements are described in Section VII, and the paper is concluded in Section VIII.

TABLE I: Literature Review of Related Work

S.No	Authors and Date	Title	Description
1	Megalingam et al., 2025	Cleaning Robots: A Review	Reviews sensor technology and smart control strategies for autonomous cleaning mechanisms.
2	Kim et al., 2019	Control Strategies	Covers reactive and smart navigation methods for domesitc purposes.
3	Dandan et al., 2016	Cleaning Confined Spaces	Proposes techniques for cleaning small tanks and silos using robotic systems.
4	Prassler et al., 2000	History of Cleaning Robots	Details of early designs of cleaning mechanisms and recent trends in autonomous cleaning.
5	Hofner and Schmidt, 1995	Path Planning	Introduces coverage techniques using path templates.
6	Ishida et al., 2012	Chemical Sensing in Robotics	Reviews integration of gas sensors and theit response systems in mobile robotics used in cleaning robots.
7	Pandey et al., 2014	Home Cleaning Survey	Surveys IR sensor-based cleaning platforms.
8	Abidin et al., 2015	In-pipe Cleaning Robot	Describes a robotic system for internal pipe cleaning using water jets.
9	Neumann et al., 1997	Complete Coverage Planning	Details a template-based planner with behavior-based tracking using ultrasonic sensors.
10	Adithya et al., 2019	Auto Cleaning and Mopping Robot	Designs a budget friendly cleaning and mopping robot using ultrasonic sensors and uses a Bluetooth control for movement.

II. Materials and Methods

A. Hardware Components

ChemBot was designed to be modular, strong, and reasonably priced. The chassis, which provides a stable foundation for mounting components, is composed of a lightweight acrylic sheet measuring 30 cm by 20 cm. Mobility is provided by four 6V DC geared motors (200 RPM), and differential steering is made possible by an L293D dual H-Bridge motor driver, which permits independent control of the left and right wheels.

Obstacle detection is handled by three HC-SR04 ultrasonic sensors, which are placed at the front and sides. They are able to recognize objects with accuracy within a 2–400 cm range. Alcohol spills are detected using a MQ-3 gas sensor module, which is sensitive to ethanol concentrations between 25 and 500 ppm. Cleaning is done with a 5V DC peristaltic pump and a nylon brush that is positioned near the sensor detection zone. The pump, which dispenses a mild detergent solution, is activated by a relay (JQC-3FF-S-Z). The entire system is powered by a 7.4V 2200mAh LiPo battery, and voltage regulators ensure that every module runs securely.

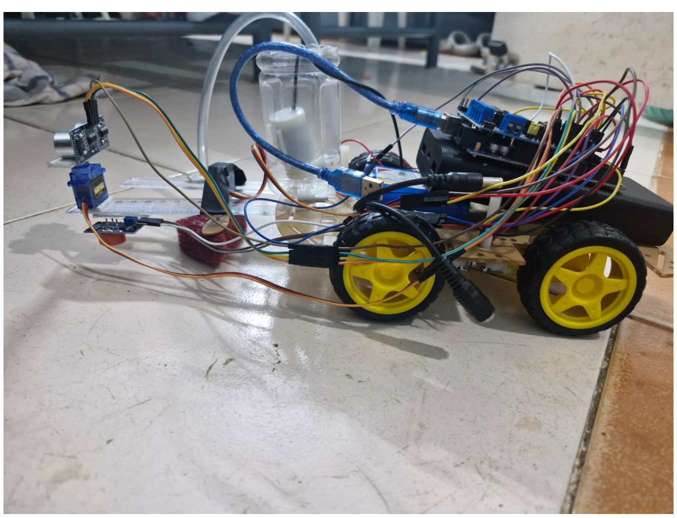

Fig. 1: Prototype of ChemBot showing the mounted sensors

The finished ChemBot prototype. Key subsystems like the MQ-3 alcohol sensor, liquid dispensing unit, control electronics, and ultrasonic navigation sensors are evidently integrated into the mobile platform. ChemBot can perform certain cleaning tasks and detect spills on its own with this configuration. Fig. 2

B. Software Components

The embedded software was made with Arduino C/C++. Because navigation employs time-based motion control that has been empirically calibrated, encoders are not necessary. Sensor interfacing modules continuously collect real-time data from alcohol and ultrasonic sensors, filtering noise to ensure sound judgment. The pump and brush subsystems are turned on to regulate the cleaning response when alcohol concentrations rise above a preset threshold. The finite state machine structure of the control logic allows for smooth transitions between navigation, obstacle avoidance, and cleaning operations. The software uses about 60

C. Methodology

Cleaning, detection, and navigation are the three primary phases of ChemBot's operation. The robot travels in a spiral pattern, progressively increasing the distance between turns to optimize coverage. When an obstruction is detected within 20 cm, it switches to wall-following mode, changing wheel speeds to keep a 15 cm clearance.

The amount of alcohol vapor in the air is continuously measured by the MQ-3 sensor. If values exceed 100 ppm, ChemBot stops, aligns itself, and starts the cleaning system, which will scrubbing the surface with a rotating brush and dispense roughly 15 ml of cleaning fluid over 5 seconds. After cleaning, the robot switches back to its previous navigation mode.

D. Experimental Setup

The experiments were conducted in a 5m $\times$ 5m indoor space, with furniture and walls serving as obstacles to simulate real clutter. Ethanol solution spills were manually placed at random locations. We observed the robot's ability to navigate, avoid obstacles, detect spills, and clean contaminated areas. Video recordings and manual inspections verified the performance.

E. Sensor Placement and Monitoring Setup

The ultrasonic sensors were set up to detect both forward and lateral obstacles, and the MQ-3 alcohol sensor was positioned close to the floor for better vapor detection. The cleaning system, which included the brush and pump outlet, was placed directly underneath the sensor to ensure precise cleaning action targeting. In order to record sensor data and robot states for later analysis, a laptop was connected via serial monitoring during the trials.

III. Proposed Method

By integrating navigation, chemical detection, and cleaning capabilities, the ChemBot robot can function independently. The navigation strategy does not require encoders or sophisticated localization systems because it is based on a time-calibrated control approach. After every 90-degree turn, the robot's forward motion durations are gradually extended in an outward spiral motion. The rotational and forward motions are calibrated using empirical timings; 90-degree turns are completed in 0.75 seconds, and forward motion of about 20 centimeters is accomplished in 2.1 seconds.

Ultrasonic sensors continuously scan the environment while ChemBot navigates. The robot transitions from spiral navigation to wall-following mode, keeping a lateral clearance of about 15 centimeters, if an obstacle is detected within a 20-centimeter threshold. By doing this, ChemBot can adjust to changing indoor conditions and maximize coverage while avoiding collisions.

In order to identify alcohol vapors during navigation, the MQ-3 gas sensor periodically takes samples of the surrounding air. ChemBot instantly stops when the sensor reading rises above a predetermined threshold of 100 ppm. After orienting itself toward the spill site, the robot activates the cleaning mechanism. A peristaltic pump is used to clean the surface by delivering a regulated quantity of detergent solution over a period of five seconds. At the same time, a revolving brush stirs the surface to guarantee that the cleaning solution is evenly distributed and scrubbed.

ChemBot returns to its exploration from the point of interruption once the cleaning cycle is finished. ChemBot provides an affordable and self-sufficient solution for focused spill control in indoor spaces by combining straightforward navigation algorithms with localized cleaning and real-time chemical sensing.

IV. Experiments and Results

A set of controlled tests were carried out in a 5-by-5-meter indoor space to assess ChemBot's performance. To create a realistic and dynamic environment, the test area was set up with chairs, boxes, and tight hallways, as well as random alcohol spills created with ethanol solutions. The purpose of each experiment was to evaluate ChemBot's capacity for self-navigating, alcohol spill detection, cleaning mechanism activation, and operation resumement without outside assistance.

ChemBot was set up at random initial positions and given free reign to explore the surroundings during the experiments. While the MQ-3 alcohol sensor readings were recorded through serial communication, the ultrasonic sensors were observed to confirm the effectiveness of obstacle avoidance. Important performance indicators were noted, including system response time, cleaning effectiveness, spill localization precision, and detection sensitivity.

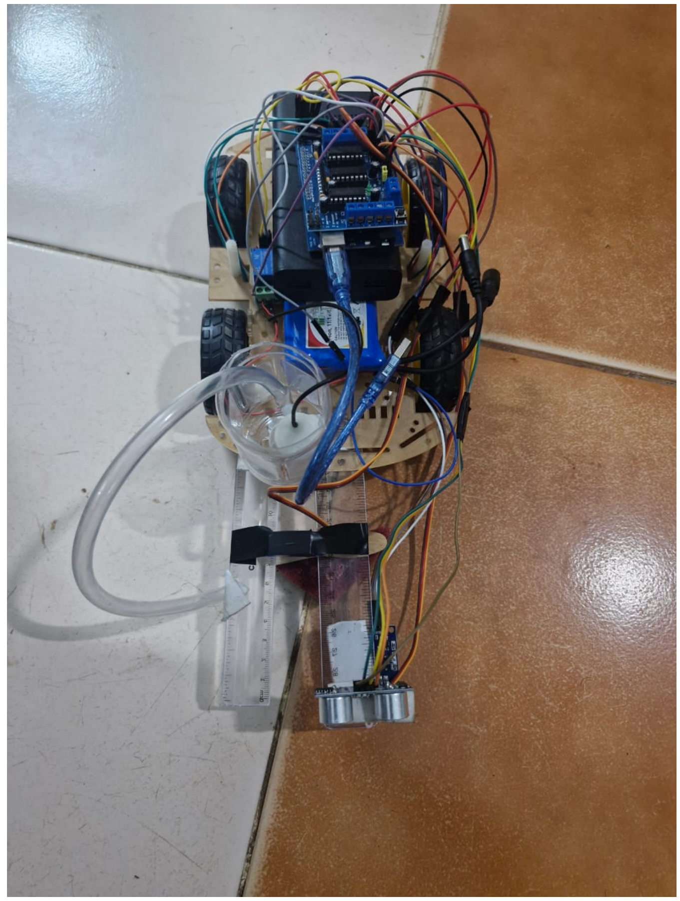

Fig. 2: Fully operational ChemBot prototype demonstrating integrated navigation, sensing, and cleaning capabilities during performance evaluation tests.

When spill zones were detected, ChemBot reliably initiated cleaning procedures and detected alcohol concentrations as low as 25 ppm. From detection to cleaning activation, the average cleaning response time was roughly 8 seconds. The robot successfully navigated around both static and dynamic obstacles without colliding, maintaining a high obstacle avoidance success rate of over 90%. Based on the spread and removal of visible spill residues, visual inspections verified that ChemBot achieved an estimated cleaning effectiveness of 85%.

Existing robotic cleaning systems from Ishida et al. [3] and

Adithya et al. [10] were compared with ChemBot's performance to previous studies. The findings show that ChemBot maintains a low hardware profile while providing enhanced alcohol detection sensitivity, quicker reaction times, and efficient chemical sensing and mechanical cleaning integration.

TABLE II: Performance Comparison of ChemBot with Existing Robots

System	Detection Threshold	Response Time (s)
Ishida et al. (2012)	50 ppm	12
Adithya et al. (2019)	N/A	20
ChemBot (Proposed)	**25 ppm**	**8**

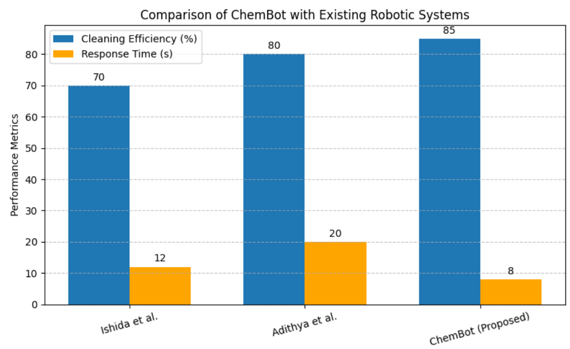

Fig. 3: Comparison of Cleaning Efficiency and Response Time across different robotic systems.

a visual graph comparing cleaning efficiency and response times is shown in Figure 3, emphasizing the advantages of ChemBot over previous designs.

V. Conclusion

The design, development, and assessment of ChemBot, an autonomous mobile robot intended to identify and clean up alcohol-based spills in indoor settings, were presented in this paper. Through the integration of inexpensive hardware components like a MQ-3 gas sensor for alcohol detection, ultrasonic sensors for navigation, and a synchronized cleaning mechanism powered by a mechanical brush and peristaltic pump, ChemBot effectively accomplishes targeted cleaning tasks with little assistance from humans. By using a time-calibrated navigation strategy, the robot avoids the need for costly localization systems like wheel encoders or LIDAR, keeping the platform as a whole affordable and usable for real-world deployment.

ChemBot's capacity to consistently identify alcohol spills with high sensitivity and carry out cleaning operations with a fast system response time of roughly 8 seconds was proven by extensive experimental validation. The robot outperformed several current robotic cleaning systems in terms of detection sensitivity, operational speed, and targeted cleaning performance, achieving an approximate 85% cleaning efficiency. ChemBot is a potential solution for preserving hygienic conditions in medical facilities, labs, and other public areas because it combines chemical sensing with responsive mechanical cleaning and obstacle avoidance via ultrasonic sensing.

Future research could concentrate on improving the navigation strategy by utilizing inertial measurement units (IMUs) or vision-based localization systems, even though the current prototype performs well in controlled indoor environments. Using multi-sensor arrays to extend chemical detection capabilities to other volatile compounds could make ChemBot even more useful for more general sanitation tasks. Real-time analytics and supervision may also be made easier by incorporating remote monitoring features through cloud connectivity. All things considered, ChemBot offers a strong platform for the creation of intelligent, self-governing cleaning systems that can react to chemical contamination in actual settings.

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