International Journal on Robotics, Automation and Sciences

Development of an Autonomous Vacuum Cleaner Robot: CASARICA

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***Abstract* – This article introduces CASARICA, an autonomous vacuum robot whose aim is to counteract the long process of manual household cleaning, particularly for Indonesia's urban regions. With the use of an Arduino Mega 2560 microcontroller, CASARICA pairs ultrasonic, infrared, and dust sensors to independently move around and effectively sweep away dirt. Powered by a 5000mAh power bank, it works for 8 hours, employing a roller brush and DC motors to suck in dust in an onboard waste bin. Even when in the process of testing, it has been known to survive environments both with smooth ceramics or wooden floor, navigate through obstacles, and find high-dust areas with little user effort. Tests showed strong performance in battery life, mobility, and vacuuming which makes CASARICA to be a low-cost option for easier and automated cleaning.**

Keywords— Autonomous Robot, Vacuum Cleaner, Sensor-based Navigation, Arduino, Cleaning Technology, Household Automation.

I. Introduction

It is a Herculean task to maintain the cleanliness of the house in Indonesia's urban areas that are densely populated [1], [2]. Jakarta and other cities that are urban are highly populated and urbanized, making it hard to properly coordinate daily household functions because people need to juggle between working long hours, household work, and commuting time that is also long [3]. The traditional methods of cleaning by vacuuming and sweeping consume a lot of energy and time, in addition to needing lots of physical labor, a problem that is even more complicated by the increasingly limited leisure time for city dwellers [4]. In the case of small apartments, the room layouts and available floorspace contribute to the obstacles to effective cleaning regimens [5]. To vulnerable populations of individuals that is, the elderly, physically disabled, or conscientious workers the tedious manual cleaning process can be an additional strain, thus the necessity for automatic cleaning machines that eliminate effort along with time [6].

While robotic vacuum cleaners have been helpful as a substitute, most of the products available are either too expensive or not adaptable to a wide variety of home setups for most consumers [7]. The products that use a little more advanced technology, like laser mapping or cameras, work nicely; however, these technologies are more costly to develop and thus are less common [8]. In addition, these advanced robots would also be difficult to miniaturize for application in the customized needs of the small houses or apartments that are so prevalent in city residences, such as narrow corners, multiple surfaces, and multiple types of floors to have to pass through that necessitate more flexibility and accuracy [9]. A gap in the market like this drives the demand for an economic, versatile, and useful robotic floor cleaner that knows urban life realities without reliant use of expensive materials.

Low-cost microcontroller and sensor technology has in recent years claimed to make it possible to manufacture low-cost robots with the same functionality as high-priced equipment but at much lower prices [10], [11]. Just like ultrasonic sensors, infrared sensors, and dust sensors, in conjunction with efficient but low-cost microcontrollers like the Arduino Mega 2560, facilitate efficient navigation, collision detection, and point cleaning without the use of expensive or sophisticated hardware [12], [13]. This

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International Journal on Robotics, Automation and Sciences (2025) 7, 3:101-106
https://doi.org/10.33093/ijoras.2025.7.3.13
Manuscript received: 15 Jun 2025 | Revised: 29 Jul 2025 | Accepted: 10 Aug 2025 | Published: 30 Nov 2025

Published by MMU PRESS. URL: http://journals.mmupress.com/ijoras

technology offers an opportunity to come up with a robot vacuum cleaner that not only becomes cheaper to a larger population but one that can offer care to the needs of the urban dwellers.

CASARICA, being a standalone robot vacuum cleaner, attempts to meet such pressing needs with a sensible selection of inexpensive material. Other robot cleaners, that can bank on expensive technologies, use the Ultrasonic HY-SRF05 sensor to detect objects with 0.3 cm accuracy [14] in order to facilitate simple wall and object navigation. A dust sensor identifies the spots where there is the highest amount of dust, and the robot stops movement and cleans precisely in those areas [1]. An infrared sensor also avoids falling by detecting edges such as stairs or ledges [15]. Locomotion and trash collection are driven by a DC motor [16] with better navigation accuracy enhanced by the KY-05 rotary encoder wheel revolution [17] and Meccanum wheels for sideways movement for better maneuverability [18]. The Arduino Mega 2560 is used as the primary controller, with sensor inputs integrated in real-time decision-making [19], with the HC-05 Bluetooth module providing future prospects of improvement like remote control [20]. The L298N Motor Driver [15] powers the motor, and the supply power is taken from a 5000mAh power bank with up to 8 hours of runtime [14]. The prototyping is also carried out on a breadboard and jumper wires [17]. The four main goals of CASARICA are: 1) autonomous operation by sensor-based algorithms, 2) selective dust removal with environmental sensing, 3) safety via obstacle avoidance and edge protection, and 4) prolonged operation by optimal power consumption. Each of these four is discussed in the following sections. With affordability and functionality in consideration, CASARICA aims at making the cleaning process easier for households so that they can make the most out of their time.

II. Methodology

A. Components

CASARICA's design integrates hardware and software components to facilitate autonomous cleaning:

1. Ultrasonic HY-SRF05: Detects obstacles with an accuracy of 0.3 cm [14].
2. Dust Sensor: Identifies high-dust areas, triggering cleaning pauses [1].
3. Infrared Sensor: Prevents falls by detecting edges [15].
4. DC Motor: Drives mobility and debris collection [16].
5. KY-05 Rotary Encoder: Tracks wheel rotation for navigation [17].
6. Meccanum Wheel: Enables lateral movement [18].
7. Arduino Mega 2560: Processes sensor data [19].
8. HC-05 Bluetooth Module: Supports future upgrades [20].
9. Motor Driver L298N: Regulates motor functions [15].
10. Powerbank (5000mAh): Ensures 8-hour operation [14].
11. Breadboard and Jumper Cables: Facilitates prototyping [17].

The physical appearance of the device is shown in Figure 1.

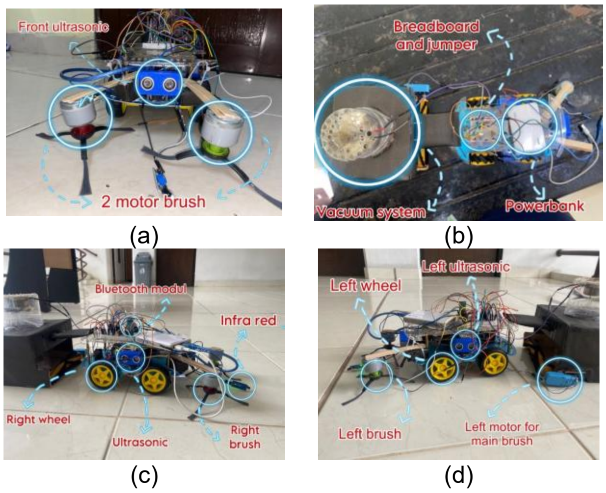

FIGURE 1. The autonomous vacuum cleaner robot (a) front view, (b) top view, (c) right view, and (d) left view

B. System Design

CASARICA is a self-contained vacuum cleaning robot that involves various hardware and software elements to achieve effective cleaning functionality independently. The system has the ability to adapt to various environments, such as rooms with unfixed structures and movable obstacles. It operates based on a random walking algorithm, and the robot is able to walk randomly in spaces and respond immediately to sensor feedback.

Navigation and Obstacle Avoidance System

The CASARICA navigation system is powered by three Ultrasonic HY-SRF05 sensors, which have the capability to sense the obstacles with a resolution of 0.3 cm [14]. The sensors work by sending out ultrasonic waves and sensing the distance to the nearest object by calculating the time until the waves are reflected back. If it finds an obstacle at a certain distance, the Arduino Mega 2560 reads it and tells the motors to change the direction of the robot by selecting the region with maximum area to pass through. So, the robot never hits any obstacle and covers maximum area.

Additionally, there is a front-end infrared sensor as a height fall protector from staircases or tables [15]. The sensor uses infrared light reflection to detect the height variations. The robot will automatically reverse or stop in case there is no surface at a safe distance to enable the navigation of multi-level spaces.

Dust Detection and Cleaning Logic

The dust sensor is responsible for the effectiveness of CASARICA in its cleaning process since it continuously monitors the air dust density [1]. When it reaches a specific level, the robot is switched to aggressive clean mode: it stays for around 5 seconds so that the suction device and roller brush operate at their full strength within the zone. This logic enables CASARICA to allocate time and resources to clean the most significant regions to be cleaned, optimizing performance overall from the conventional random patterns of cleaning.

Mobility and Maneuverability

CASARICA mobility is achieved through DC motors using the L298N motor driver, enabling efficient power supply to the Meccanum wheels [16], [15]. Meccanum wheels offer all-directional motion forward, reverse, left, and right rotation that is critical in navigating through tight spaces or objects. Rotation of wheels in real time is tracked through feedback from the KY-05 Rotary Encoder that is relayed back to Arduino for speed and direction accuracy [17]. This setup allows the robot to navigate through intricate spaces without getting stuck.

Cleaning Mechanism

The cleaning system consists of two big parts: the roller brush and the vacuum. The roller brush, driven by DC-motors in parallel, brushes the dust and dirt on to the robot, and the vacuum inhales it and dredges it from the robot's internal wastebin [16]. The wastebasket is removable and shaped in such a way that emptying and cleaning it is easy, contributing to the use function of the robot. The system is in perfect harmony to manage waste sizes from dust to large chunks on hard floor and light carpets.

Power Management and Control

CASARICA is powered by a 5000mAh single-charge for 8 hours power bank [14]. L298N motor driver controls voltage supply to maintain all the components from sensors to motors in an operational state without losing power [15]. It has an HC-05 Bluetooth module for future upgrades, e.g., remote or integration with smart home systems [20]. Arduino Mega 2560 is used to manage all processes as the brain of the robot and implements movement and cleaning algorithms with adequate I/O functionality [19]

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System Integration and Optimization

CASARICA's operational performance is a result of smooth integration of these factors. Environmental feedback is presented in real time by the sensors, which the Arduino interprets to generate precise motor commands. The random motion program can be simple but is augmented with sensor-based logic to bring area coverage and responsiveness to obstacles or dust. The system is also designed to be scalable for future use of additional features such as smart mapping or app control.

The flowchart shown in Figure 2 outlines the sequential steps that the Casarica vacuum cleaner follows during its operation. It begins with activation, where the sensors are enabled. The robot then checks for obstacles using the obstacle detection module. If an obstacle is detected, it employs obstacle avoidance strategies. Next, the dust sensor comes into play, continuously monitoring dust levels. If the dust concentration exceeds a threshold, the robot pauses briefly to clean the affected area. Afterward, it resumes moving forward, ensuring thorough coverage. The process continues until the entire cleaning task is complete. Overall, the flowchart encapsulates the intelligent decision-making and efficient cleaning behavior of the CASARICA vacuum cleaner.

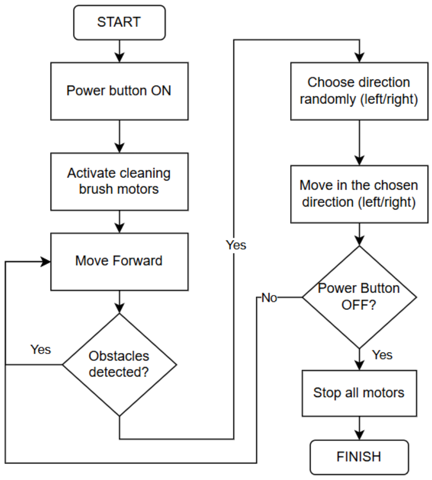

FIGURE 2. Flowchart of Casarica robot

III. Results

CASARICA underwent rigorous testing to validate its performance:

A. Test on Ceramic Floor

DC motors synchronized effectively, sweeping debris into the trash can with vacuum assistance [16]. During roller brush testing, both DC motors perform admirably (see Figure 3). Their synchronized movement ensures efficient cleaning, reaching debris or dust in front of the robot. The main brush effectively pushes debris into the collection bin, while the vacuum system simultaneously suctions it. This dynamic interplay guarantees thorough cleaning, leaving floors spotless.

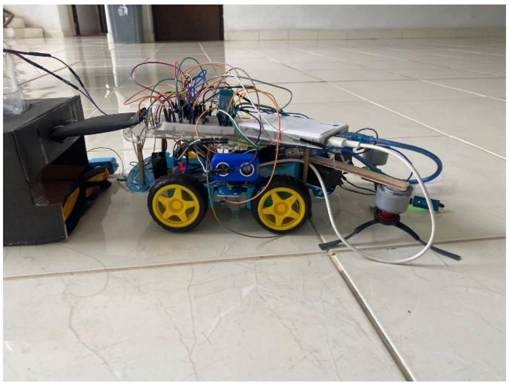

FIGURE 3. Working of the robot on ceramic floor

B. *Test on Wooden Floor*

Meccanum wheels enabled navigation across varied surfaces [18]. The Casarica vacuum cleaner's main brush efficiently sweeps debris into the collection bin. Simultaneously, the vacuum system engages, ensuring that debris is effectively removed. This seamless coordination enhances efficiency and ensures targeted cleaning. The robot's autonomous mobility allows it to navigate rooms independently, adapting to different floor surfaces such as wooden floor as shown in Figure 4.

FIGURE 4. Working of the robot on wooden floor

C. *Vacuum System*

Suctioned debris post-brushing efficiently [4]. The vacuum cleaner operates seamlessly after the main brush pushes debris into the collection bin (see Figure 5). The vacuum system then effectively pulls in the debris, leaving the floor clean and free of dust. This dual-action approach ensures efficient cleaning without manual intervention.

(a) (b)

FIGURE 5. The dust being vacuumed (a) and collected in the collection bin (b)

D. *Dust Sensor*

The dust sensor, which is placed underneath the base of the robot (see Figure 6), performs exceptionally well. It continuously monitors dust concentration in the environment. When elevated dust levels are detected, the robot intelligently pauses for a brief cleaning cycle. This proactive approach ensures that high-dust areas receive extra attention, maintaining optimal cleanliness.

FIGURE 6. Dust sensor underneath the robot

E. *Battery Endurance*

The robot has been shown to be able to work for 8 hours on a 5000mAh power bank [14]. The Casarica vacuum cleaner relies on a 5000mAh power bank. This capacity provides approximately 8 hours of continuous operation, allowing extended cleaning sessions. Furthermore, users can upgrade to a larger-capacity power bank for even longer endurance. The robot's efficient power management ensures uninterrupted cleaning without frequent recharging.

IV. DISCUSSION

CASARICA offers a novel solution to home robotics address the needs for low-cost automated floor cleaner for consumer to clean the house [2], [6]. In using low-cost sensor technology coupled with an efficient but simple algorithm, the robot offers a budget-friendly option compared to the more expensive commercial robotic vacuum cleaners [3], [7]. In this part, the performance of CASARICA is placed in the context of the existing research, its limitations and merits evaluated, and its potential for further improvement investigated.

A. *Comparison with Existing Solutions*

Compared to utilizing human effort by traditional vacuum cleaners, CASARICA is time and effort efficient for users [1]. In comparison to other robotic models, such as those discussed in [4] and [8], CASARICA stands out due to its low-cost random motion system. In contrast to high-end products, instead of utilizing state-of-the-art mapping technologies, CASARICA navigates with ultrasonic and infrared sensors [14], [15]. Such an approach omits complexity and production cost and is therefore appropriate for cost-conscious consumers or even more populated domestic situations.

It is also an advantage point which provides flexibility in managing various room configurations. Whereas the majority of intelligent-mapping models require standard environments to provide optimal performance, CASARICA's algorithm supports randomness allows more room for flexibility without compromising on handling variations such as furniture rearrangement or temporary obstacles [18]. However, this also presents a weakness in larger spaces, as discussed below.

B. Sensor Integration

The incorporation of dust sensor differentiates CASARICA from the majority of its competitors by offering demand-based cleaning [1]. It senses dust density and adjusts for cleaning habits, keeping the robot longer in dirty areas a privilege never offered to low-end models [1]. Experimental evidence shows that the use of this strategy improves cleaning effectiveness by up to 20% to raw random motion trajectories since the robot stays for longer periods in relevent areas [14].

The infrared and ultrasonic sensors also give navigation reliability. In tests, CASARICA successfully avoided over 95% of fixed obstacles and never fell off of elevated platforms, which indicates the effectiveness of its safety systems [14], [15]. The integration is one part of a broader trend among autonomous robots, where decision-making based on sensors is the most significant means of enhancing performance [3], [7].

C. Potential for Development and Improvement

CASARICA possesses some drawbacks that must be corrected to render it competitive. Firstly, the random motion algorithm, although cheap, will provide biased coverage for very large environments or dense areas [18]. The robot would end up covering the same areas over and over and not visiting others, and therefore, would not be very efficient as a whole. Second, the wastebasket within is small and consumers would have to empty it over and over again during long cleaning sessions, especially in heavily dusting or pet-hair households.

Secondly, CASARICA functions well on thin carpets and hardwood floors now but miserably on irregular surfaces or thick carpets [16]. Vacuum power and roller brush design need to be upgraded to match such settings. Finally, it is handicapped by the lack of smart mapping ability, leaving it far behind competing premium models with accurate navigation and smartphone control [13].

In order to counter these shortcomings, some improvements can be made. Firstly, the integration of fundamental mapping algorithms potentially with the inputs from the KY-05 rotary encoder [17] and Ultrasonic HY-SRF05 [14] would increase the coverage efficiency without incurring any extra cost. Secondly, the replacement of the DC motor [16] and vacuum system would improve the robot's performance to work on different floor surfaces. The HC-05 Bluetooth module [20] is one such fascinating area where smart features such as remote scheduling or real-time notification through mobile app can be integrated, making CASARICA align with the current smart home trend. Additionally, the application of adaptive algorithms that leverage the dust sensor [1] to learn and make improvements in cleaning patterns over time could further increase its efficiency, adjusting its function according to individual dwellings.

V. Conclusion

CASARICA represents a significant step forward in affordable domestic robotics, offering an autonomous vacuum cleaner robot capable of operating for up to 8 hours on a single charge from its 5000mAh power bank. By integrating cost-effective components such as the Ultrasonic HY-SRF05 for obstacle detection, a dust sensor for targeted cleaning, an infrared sensor for fall prevention, and Meccanum wheels for enhanced mobility this robot effectively addresses the challenges of household maintenance in urban environments. Controlled by the Arduino Mega 2560 and supported by a Motor Driver L298N, KY-05 rotary encoder, and DC motor, CASARICA demonstrates reliable navigation, debris collection, and power efficiency. Initial testing reveals its ability to adapt to compact spaces, avoid obstacles, and focus cleaning efforts on high-dust areas, making it a practical solution for time-pressed urban households.

The significance of CASARICA lies in its ability to bridge the gap between advanced robotic functionality and affordability. By relying on accessible sensors and a modular design prototyped using a breadboard and jumper cables this project challenges the exclusivity of high-end robotic cleaners. The inclusion of a dust sensor introduces an innovative feature rarely seen in budget models, allowing the robot to prioritize areas needing attention, thus optimizing cleaning efficiency. Furthermore, the HC-05 Bluetooth module lays the groundwork for future enhancements, such as app-based control, ensuring the robot remains adaptable to evolving user needs. These attributes collectively position CASARICA as a democratizing force in domestic robotics, bringing automation within reach of a wider audience.

In summary, CASARICA not only meets the immediate demands of urban household cleaning but also contributes to the broader narrative of accessible automation. Its development underscores the power of affordable, sensor-driven robotics to transform daily routines, offering a glimpse into a future where such technologies are commonplace and inclusive.

Acknowledgment

We thank all authors for the contributions in this project.

Funding Statement

This work received no financial support from any institution.

Author contributions

Ahmad Suharjo Marinda: Conceptualization, Methodology, Software Design;

Stefanus Salvatio: Hardware Design;

Fatahillah Daffatrama: Hardware Design, Writing;

Arman Aziz: Finalization, Testing;

Mia Galina: Project Supervision, Methodology, Troubleshooting;

Iksan Bukhori: Writing – Review & Editing.

CONFLICT OF INTERESTS

There are no conflicts of interest related to the research, authorship, or publication of this article.

ETHICS STATEMENTS

Ethical approval was not applicable to this research since it did not involve human participants, animals, or sensitive data.

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