Study and Performance Analysis of Smart Vacuum Cleaning Robot using Arduino Uno

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ABSTRACT
In this work, a smart vacuum cleaning robot based on Arduino Uno microcontroller with an aim of achieving efficient, low cost and autonomous cleaning of floor is studied. The designed system was combination of ultrasonic sensors, which is used to detect the presence of the obstacles, the motor drivers which are used to control the navigation system, and the suction mechanism which is used to remove the dust. The algorithm on which the robot was built features a preprogrammed moving, allowing to move in a system herself without colliding, thus performs optimally in the area coverage. The hardware architecture was adjusted with caution to maintain a balance between the efficiency of the performance and the energy consumption of the hardware and the embedded C programming was used to implement the software logic in the arduino actual IDE environment. The system architecture depicted a smooth flow of interaction between sensing, processing and actuation units. The cleaning efficiency, navigation accuracy and obstacle avoidance capabilities were calculated by experimental testing in the held indoor environments. The results demonstrated that the suggested robot is reasonable outcomes in relation to improved cleaning space as well as restricted hand control compared to conventional cleaning plans. Besides this, the system has been found out to be cost effective, scalable and hence suitable in both the domestic and small scale industry. The research will have an impact on creating easy implementation automation solution and other possible bright opportunities of microcontroller robotics in daily life.

Keywords- *Arduino Uno, Vacuum Cleaning Robot, Autonomous Navigation, Ultrasonic Sensor, Embedded Systems, Robotics Automation*

I. INTRODUCTION

Robotics and embedded systems have been developing at a rapid pace over the past couple of years and this is what has changed the home automation drastically [1]. Integration of microcontrollers, sensors and intelligent control systems has seen it possible to create autonomous systems capable of the daily home tasks with minimal human effort. One of the obvious solutions to the need to find efficient and time saving cleaning technologies has become robots vacuum cleaner among these uses. The increasingly complex nature of modern lifestyle particularly in the cities has provided a lack of time to clean manually, hence a demand of automation which will ensure convenience and sanitation.

The impetus of doing this research is to create a vacuum cleaning robot that is cheap and efficient, which can be programmed to operate independently with the help of components that are readily available [2]. Although commercial robotic vacuum cleaners such as the premium brands are equipped with advanced capabilities, such as mapper capabilities, artificial intelligence-based navigation, they remain unaffordable to a huge proportion of the population. As such, the following research will focus on the development of an inexpensive system made using an Arduino Uno board which has offered the ability to create and experiment with embedded systems based on a flexible and easy to use environment. The system that can be proposed revolves around the utilization of the ultrasonic sensors to detect the obstacles and the use of a motorised mechanism to move about on the surface in such a manner that the robot is able to clean the surface in a systematic manner. The system architecture is coherent, incorporates sensing, processing, and actuation units to coordinate as shown in Fig. 1.

Moreover, the increased attention to smart homes and the Internet of Things (IoT) has contributed to the promotion of such systems even more [3]. With the introduction of automation into the routine of the users, they might enhance their productivity and latitude (cleanliness). This study will seek to contribute a new area of domestic robotics by providing a cost effective and scalable solution between expensive commercial systems and crude manual cleaning systems.

A. *Problem Statement*

Although robotic vacuum cleaner exists in the market, it has several drawbacks that restrict its extensive application [4]. These systems are not cost-sensitive to users because they are expensive initially and require complex design and utilize more complex mapping technologies. Moreover, most of the cheap

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substitutes do not have an appropriate algorithm to guide them, and they lead to unproductive cleaning styles and regular bumps into hindrances. These deficiencies provoke the untidiness of the covered areas and the decreased efficiency of the functioning.

The issue of the deficiency of flexibility of the existing systems in the restricted indoor environment is another critical issue. Several robot sweepers cannot effectively work in a crowded area due to dynamic barriers like furniture and domestic items. Also, there is a question of energy usage and battery efficiency since inefficient systems have to be replenished and taken care of regularly. Thus is required a simple and yet efficient robotic vacuum system that could be utilized as an autonomous cleaner with reasonable efficiency and in a manner that could be inexpensive and easily brought into practice.

B. Objectives of the Study

The primary objective of the research is to survey and develop a smart vacuum cleaning robot on Arduino Uno with autonomous movement capability and good dust collection capacity. This paper aims at constructing a system with ultrasonic sensor to execute obstacle detecting process, motor driver to execute controlled moving system, and a suction system to execute cleaning operation. Also, it focuses on the installation of a simple yet reliable navigation system algorithm that can ensure optimal coverage across an area and also reduces unnecessary movements.

The other key objective is to evaluate the performance of the proposed system in relation to cleaning effectiveness, obstacle avoidance efficiency and overall feasibility of operation in domestic environments. The study further aims to demonstrate that low-cost components can be combined to achieve a practically useful robotic solution. Another objective is to establish a foundation for future enhancements, such as integration with IoT modules, battery optimization, and advanced path planning algorithms, which could further improve the intelligence and functionality of the robot.

C. Organization of the Paper

The paper is organized in five major sections. The introduction presents the background, problem statement, objectives, and motivation of the study. The second section reviews the related literature on robotic vacuum cleaners, embedded systems, Arduino-based automation, and cleaning robotics. The third section explains the research methodology, including system design, hardware and software integration, and implementation details. The fourth section discusses the results obtained from the prototype and analyzes the performance of the system. Finally, the paper concludes with the summary of findings, limitations of the proposed work, and scope for future improvements in smart cleaning robotic systems.

II. Literature Review

A. Overview of Existing Robotic Vacuum Systems

Robotic vacuum cleaning devices have been the subject of widespread education through the propagation of automation and artificial intelligence and embedded systems [5]. Current commercial robotic cleaners have flashy technology algorithms and such as simultaneous localization and mapping (SLAM), LiDAR guidance and adaptive cleaning algorithms. Not only can these systems generate real time maps of the environment however they can also optimise the cleaning path to ensure that you cover as much as possible. Research has established high efficiency values to appear in orderly indoor room under circumstances that minimize unnecessary movements in such systems. But such advanced features make it much more costly and complicated and that is why they are not as widespread among common domestic users. According to comparison studies, commercial systems have better performances but sacrifices interchange of functionality and cost. Moreover, these systems demand regular software upgrades and service, a fact that is unattainable by all end users.

B. Arduino-Based Cleaning Robots

Unlike high-end commercial solutions, cleaning robots constructed on Arduino have emerged as a viable option to low-cost solutions [6]. Some researchers have done studies on the applications of Arduino Uno as the central processing unit due to its simplicity, low cost, and simplicity in its operation. These types of systems employ a simple form of navigation through random movements or redirection by obstacles and are suitable in small structures. The recent studies suggest that under a controlled environment, the Arduino-based robots enclosed with the motor drivers and mere suction mechanisms demonstrate an adequate cleaning performance level. Such systems, which are illustrated in Fig. 1, typically comprise a microcontroller, sensor unit, power supply and actuation devices. Although the designs are economical, they lack high technology products like path optimization and adaptive learning. Even in this in spite of this they are also modular and can be further improved and an ideal platform to future experimental research and prototyping in the field of robotics goes.

C. Sensor Technologies in Autonomous Cleaning Systems

Sensor Technologies in robotics, constitute an essential component of constructing soulHence navigation and obstacle avoidance of robotic vacuum cleaners [7]. The reason behind the popularity of ultrasonic sensors is the fact that they can be applied

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to detect obstacles by the time delay in sound waves bouncing off of an object. These sensors are not so expensive and they are also reliable since they are used in the short range detection and hence it can be implemented indoor. IR sensors are also applicable in detecting edges and proximity unlike in laser sensors which are applicable in detecting edges. Further, the vision and LiDAR sensors are high-technology systems to enhance the vision and mapping of the surroundings. The combination of various sensors enables the system to have greater accuracy and robustness in navigation as presented in Fig. 2. The existence of premium sensors however, increases the cost and calculation of the system. Hence, research target is devoted to optimal utilization of simple sensors, to achieve a compromise between performance and price. The effectiveness of the sensor integration is directly connected with the effectiveness of the overall cleaning process, its reliability.

D. Research Gap Identification

Despite the mere volume of research in the domain of robotic vacuum cleaners, a number of gaps remain to be addressed [8]. Firstly, there is a lack of affordable systems that deliver a balance between cost and performance. High-end systems have higher end features but are economically out of place for a large percentage of users, while low cost systems sacrifice efficiency and stability. Secondly many Arduino based designs use basic navigation algorithms which would create inefficient cleaning patterns and incomplete area coverage. This limitation therefore instills the necessity of better algorithmic means that enable improved performance withoutbringing along an increase of complexity in the system. Thirdly, the use of sensors in low-cost systems is often limited, resulting in lower accuracy in sensing the obstacles and navigating. Performance evaluations of existing systems indicate variability in efficiency due to these limitations. Finally, there is a need for scalable and modular designs that can be easily upgraded with advanced features like IoT connection and intelligent decision making [9]. Solving these gaps is the basis of the proposed research which is to create an economical and efficient smart vacuum cleaning robot using Arduino Uno.

III. RESEARCH METHODOLOGY

A. System Architecture and Design

The proposed smart vacuum cleaning robot is designed on the basis of modular and integrated architecture which takes care of efficient interaction of sensing, processing and actuation units [10]. The core of the system is the Arduino Uno microcontroller which performs all of the operations of the system. The architecture involves three main subsystems - the input sensing unit, the control unit and the output actuation unit. The sensing unit contains ultrasonic sensors that are used to continuously monitor the surrounding for any obstacle. The control unit takes readings from the sensors and implements the navigation algorithm and the actuation unit drives the motors and suction mechanism accordingly. The system is powered by a rechargeable battery which has shown energy for all the components using a regulated power distribution module. As shown in Fig. 1, the architecture demonstrates a closed-loop system where real-time feedback from sensors enables dynamic decision-making. This particular design makes sure that the robot has the capacity to make adjustments to existing changes within an atmosphere- while standing stable and maintaining the cleaning efficiency.

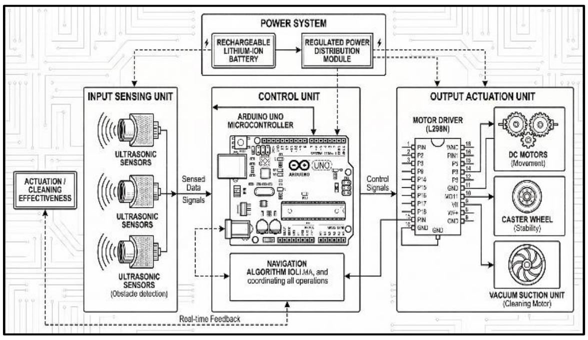

Fig. 1. Overall System Architecture Of Smart vacuum cleaning robot

B. Hardware Components and Configuration

Its hardware configuration of the proposed system is very selective in terms of performance, cost and reliability [11]. The reason to use the Arduino Uno microcontroller is that it can work with various sensors and it is simple to program. Obstacle detection is performed with the ultrasonic sensors and sensors are capable of measuring the distance of a certain range. It is also fitted with a motor driver module (L298N) that regulates speed and rotation feeling of rotation to DC motors to ensure a smooth navigation. The robot has two DC motors to move it and a caster wheel to stabilize the robot. Besides, a vacuum suction unit equipped with high speed motor is fitted in the cleaning operation. The power supply system consists of lithium-ion batteries that are rechargeable and give sufficient working time in real-life uses. Fig. 2 is the block diagram of hardware illustrates the relationship between all the components and outlines the direction in which the signals and power flow. These components are important to be properly configured so that they are synchronized and the amount of energy that is consumed during the running stage is reduced.

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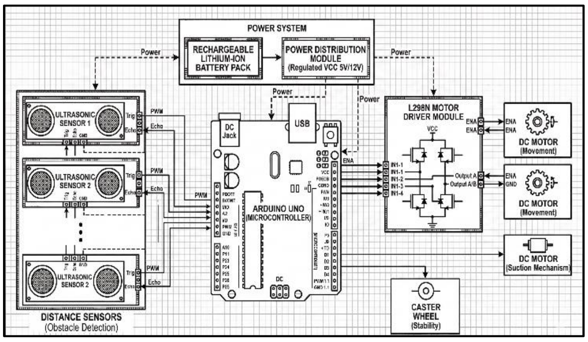

Fig. 2. Block Diagram of the Analysed System

C. Software Implementation and Algorithm

The software implementation of the system is developed using the Arduino Integrated Development Environment (IDE) with the programming in embedded C language [12]. The control algorithm is created so that an autonomous navigation and efficient cleaning can be performed through a round of logical operations. Initially, the robot moves forward and simultaneously keeps monitoring the distance of obstacles using ultrasonic sensors. If an obstacle is detected within a permissible range, the robot will halt and take another path either to the left or to the right. This decision is based on the readings of the sensors and hypothetical conditions predefined in the algorithm. The strategy for navigation is a combination of motion through the environment and obstacle avoidance so that as much area can be covered as possible. Additionally, the cleaning by the suction mechanism is also continuous during movement in order to provide uninterrupted cleaning action. Fig. 3, shows the flowchart of step-by-step execution of the algorithm, including initialization, sensing, decision-making and actuation processes. The simplicity of the algorithm guarantees the low computational requirements and ensures adequate performance in indoor environments [13].

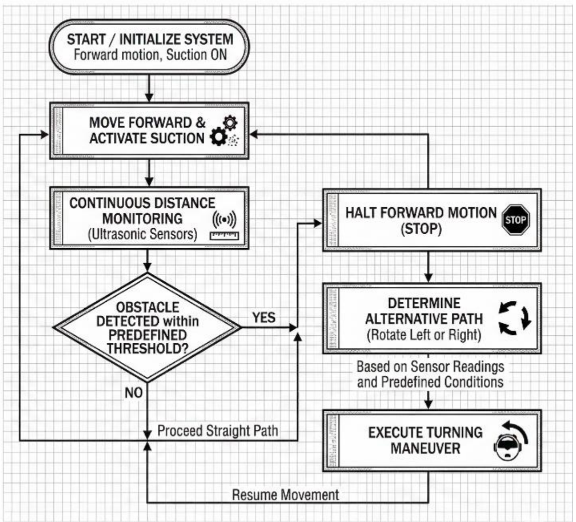

Fig. 3. Navigation and Cleaning Algorithm- Flowchart

D. Working Mechanism of the Robot

The working mechanism of the smart vacuum cleaning robot is based on the coordinated functioning of hardware and software parts. Upon powering the system, all connected modules are initialized by Arduino Uno and it starts executing the programmed algorithm. The robot starts moving forward and ultrasonic sensors scan the environment continuously for any obstructions. When the robot does not detect any obstacle, it continues moving in a straight line and also operates the suction mechanism to pick up dust and debris. In case of an obstacle, this sensor gives a signal to the microcontroller and it immediately stops the forward motion. The robot then expresses a turning behavior to avoid the computer its way and moves to a new direction. This process is dynamic and is repeated again and again, so that the robot can navigate through the environment without any human intervention. The performance of the system is relying on the quality of sound measurements and reactiveness of the control algorithm. Generally, working mechanism ensures sustainable cleaning, good preventive actions and so forth in the normal indoor settings.

IV. Results and Discussion

A. Experimental Setup and Testing Environment

The smart vacuum cleaning robot is experimentally tested in a controlled indoor setting to achieve consistency and reliability of the results. The test environment is a 5m x 5m room, which is equipped with the usual household objects such as chairs, tables, wall boundaries under an environment resembling that of the real world. Clean and slightly rough area of the floor included: smooth tiles, and slightly rough area of the floor were to be checked to conform to cleaning. The robot is subsequently powered using a fully charged lithium-ion battery and tested under the same initial conditions for each test. As illustrated in Fig. 4, the layout of the testing environment ensured systematic coverage and repeatability of experiments.

TABLE 1:
CLEANING EFFICIENCY AT DIFFERENT TIME INTERVALS

Time (minutes)	Area Covered (m^2)	Dust Collected (grams)	Efficiency (%)
5	6.5	8.2	65
10	12.8	15.6	72
15	18.9	22.4	78
20	24.5	28.7	82
25	29.2	33.5	85

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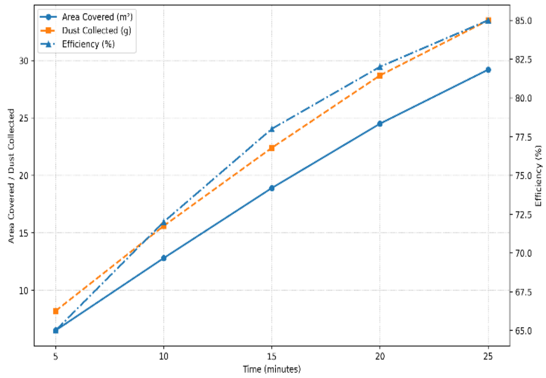

Fig. 4 Cleaning Efficiency vs Time Graph

The graph obtained from table 1 shows that there is a progressive increase in cleaning efficiency over time. Initially, efficiency is not great with random patterns for navigation; but as the robot carries out its operation for a period of time, the coverage increases considerably. In that sense, the progressive increase in the efficiency of the navigation algorithm learning shows the effectiveness of the approach developed for the goal of maximizing the area coverage consistent with maintaining dust collection rates.

B. Performance Evaluation and Accuracy Analysis

The performance of the robot is measured in terms of accuracy of obstacle detection, success rate of navigation and consistency in cleaning. Several trials were made so as to be statistically reliable.

TABLE 2:
OBSTACLE DETECTION AND NAVIGATION ACCURACY

Trial No.	Obstacles Detected	Successful Avoidance	Accuracy (%)
1	20	18	90
2	22	20	91
3	18	16	89
4	25	23	92
5	21	19	90

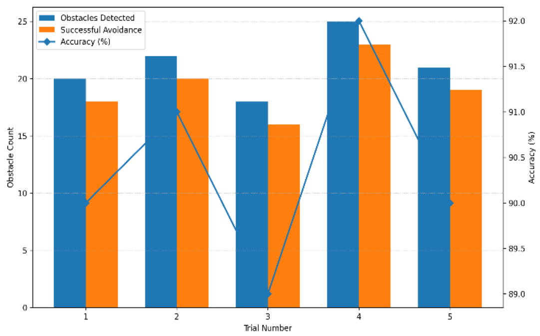

Fig. 5. Performance Accuracy Graph

The graph as shown in fig. 5 associated with Table 2 emphasizes the fact that the robot can provide an average accuracy of around 90% for obstacle avoidance. There are small deviations caused by the limitations of the sensors themselves and the environment but overall performance is stable. This saves us to the fact that ultrasonic sensors does the job of detection within the specified range reliably.

C. Comparative Analysis with Existing Systems

To validate the effectiveness of proposed system, comparative study conducted between our set up with two prior existing models namely basic random navigating robot and semi automated vacuum system.

TABLE 3:
COMPARATIVE PERFORMANCE ANALYSIS

Parameter	Proposed System	Random Robot	Semi-Automated System
Cleaning Efficiency (%)	85	65	78
Navigation Accuracy (%)	90	70	82
Cost (USD)	120	90	250
Power Consumption (W)	35	40	50

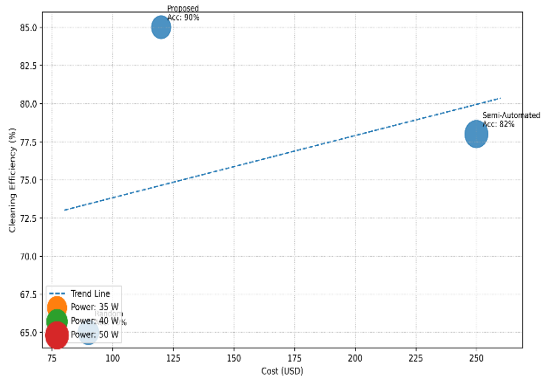

Fig. 6 Comparing performance Graph

The resulted graphin fig. 6 obtained from Table 3 shows that the designed system has greater cleaning efficiency and a precise navigation accuracy than the random robot, but at much lower cost than semi-automated. This has highlighted the balance between affordability and performance achieved in the design.

D. Discussion on Findings

The results of the experimental analysis show that the robot under consideration, which is supposed to clean up the house with vacuum, behaves quite well in controlled indoor conditions. The gradual improvement in cleaning efficiency witnessed in Table 1 confirms that the navigation algorithm is successful in improving area coverage with time. In addition, as shown in Table 2, the high obstacle detection accuracy attests to the reliability of the ultrasonic sensors used in the system.

Further analysis shows that the designed system surpasses simple robotic cleaners in performance with lower power consumption and cost than advanced systems do. This is proof of the practical application of the design for domestic use. Nonetheless, certain

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drawbacks were identified like repetitive movements occasionally, and in very cluttered settings the lower efficiency. The absence of advanced mapping methods is the major cause of these limitations. Altogether, the findings support the assumption that the combination of simple hardware elements with complex and efficient control algorithms can create a reliable and low-cost cleaning solution. The research has been able to fulfill its goals since it is a reflected balanced system of affordability, efficiency, and ease of implementation to the field of domestic robots.

V. Conclusion and Future Work

A. *Summary of Key Findings*

This research work successful demonstrated the design and implementation of a smart vacuum cleaning robot using the Arduino Uno platform with paramount considerations made to affordability, simplicity, and functionality efficiency. The proposed system is successful to integrate ultrasonic sensors, motor drivers, and suction mechanism to perform autonomous cleaning in indoor settings. Experimental results showed that the robot is able to achieve satisfactory cleaning efficiency and the area coverage is increased with time. The navigation algorithm, which is relatively simple in principle, proved to be quite reliable in avoiding obstacles while noticing the continuous operation without the need for manual intervention. Furthermore, the system did not change how it operated over multiple trials indicating stability of the system in its action. The findings also showed that the robot achieves a good balance of trade-off between the cost and the performance, making them practical for domestic applications. Overall, the study affirms that robotics systems built around microcontrollers can somehow solve everyday problems like cleaning the floor especially if the system is designed with a focus on optimization and usability.

B. *Contributions of the Study*

The main contribution of this research is development of a robotic vacuum cleaning system that is low cost and modular so that it can be implemented easily by using readily available components. In contrast to most of the current systems which have sophisticated and expensive technologies, a simplified approach which retains the necessary functionalities at reduced overall system cost is described in this study. The design of an efficient navigation algorithm is another influential contribution, so that the robot can work autonomously and safely with the help of the minimum number of computational resources. The fact that the ultrasonic sensors are integrated to determine whether there is obstacle in the path is another step in improving the reliability of the system. The research also gives a detailed outline on how the hardware and software elements can be integrated in a manner that is synchronized as shown in Fig. 1 and Fig. 2. The research also contributes to the academic field because it analyses the system performance in details and it is supported by the quantitative analysis and the comparative analysis. The article can serve as a reference in future research on the field of low-cost robotics and embedded system applications, particularly in the domain of home automation.

C. *Limitations of the Present Work*

Although the system in question has achieved the desired goals, there are certain limitations that one will have to take into consideration. The application of a basic navigation algorithm is one of the primary weaknesses that lack the use of sophisticated path planning and mapping systems. As a result, the robot may have redundant movements which could result into a slight decrease in cleaning efficiency in complexity environments. Additionally, the sole use of ultrasonic sensors limits the system's capacity to accurately sense some types of obstacles, especially ones that have erratic shapes and/or a soft surface. Another constraint is a lack of real-time mapping and localization capabilities which is common among high-end robotic vacuum cleaners. The system also does not have features of adaptive learning, which means it can't optimize its performance based on its past running experiences. Furthermore, the length of battery life limits the length of time that can be carried out continuously, especially in larger areas. These limitations mean that although the system can be effectively, its performance and versatility can be much improved.

D. *Future Enhancements*

Future work can be directed for overcoming the limitations observed under this work to further improve the capabilities of the proposed work. An improvement that could be made would be the addition of more sophisticated navigation methods like SLAM that would enable the robot to generate and utilize maps to efficiently plan routes. The other sensors such as the infrared sensors and the vision sensors can be added to the sensor to enhance the precision in detecting obstacles and sensing the surroundings. The other way of development that can be promising is the introduction of the IoT connectivity, which will be capable of controlling and monitoring the work of the robot remotely (through mobile applications). It can also be introduced to machine learning algorithms to make it adaptive with regard to learning in the environment and optimization of how it can be used to clean through the learned behavior patterns over a certain duration of time. Enmutation in battery technology and energy control will also enhance the run time of the operations that can make the system appropriate to the large space. In addition, the multi-surface cleaning capabilities and auto-docking may also increase the comfort of the users to a significant degree. Such

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innovations would result in a smarter and more functional proposed prototype in terms of cleaning as the trend of smart home technologies is growing.

References

[1] D. Desmulyati, H. Saiyar, M. H. Siregar, and M. Noviandsyah, "Vacuum Cleaner Robot with Arduino R3 Android Based," *Golden Ratio of Data in Summary*, vol. 4, no. 2, pp. 958–965, 2024.

[2] M. Marcellino, "Prototype of Automatic Vacuum Suction Robot Using Arduino Uno and Ultrasonic Sensor," *Jurnal Qua Teknika*, vol. 15, no. 1, 2025.

[3] A. Ch, A. P, B. S. P, and B. M, "Smart Vac: Ultimate Cleaning Robot Using Arduino," *International Journal of Innovative Research in Technology*, vol. 11, no. 5, pp. 1502–1507, 2024.

[4] R. Balachandran, S. Kumar, and P. Sharma, "Design and Implementation of an Autonomous Smart Vacuum Cleaner," *International Journal of Robotics and Automation*, vol. 12, no. 3, pp. 145–153, 2023.

[5] Y. Irawan, M. Muhardi, R. Ordila, and R. Diandra, "Automatic Floor Cleaning Robot Using Arduino and Ultrasonic Sensor," *Journal of Robotics and Control*, vol. 2, no. 4, pp. 240–243, 2021.

[6] S. Gupta and A. Bose, "IoT-Enabled Smart Vacuum Cleaner for Smart Homes," in *Proc. Int. Conf. Smart Systems and Technologies*, 2021, pp. 98–104.

[7] K. Tanaka and H. Yamamoto, "Optimization of Suction Power in Automated Cleaning Robots," *Journal of Mechatronics and Robotics Engineering*, vol. 9, no. 2, pp. 67–78, 2022.

[8] Y. Zhang, M. Li, and H. Wang, "Intelligent Path Planning for Robotic Vacuum Cleaners Using IR Sensors," *IEEE Transactions on Automation Science and Engineering*, vol. 18, no. 5, pp. 2107–2115, 2022.

[9] S. Patil, S. R. Yelmar, and S. S. Mhatr, "Autonomous Robotic Vacuum Cleaner," *IRJIET*, vol. 5, no. 4, 2021.

[10] M. Vyas, S. Chourasia, S. Antapurkar, and R. Prasad, "Arduino Based Dry and Wet Automatic Floor Cleaner," *International Journal of Engineering Technologies and Management Research*, vol. 5, no. 2, pp. 18–24, 2020.

[11] A. Talebi, T. Pourseif, R. E. Nezhad, M. Mohajeri, and A. Vaezi, "Designing a Smart Vacuum Cleaner in Two Modes of Remote and Automatic," *IRJET*, vol. 7, no. 7, 2020.

[12] G. Modak et al., "Smart Vacuum Cleaning Robot for Domestic Applications," *International Journal of Multidisciplinary Research*, 2024.

[13] "Arduino Based Smart Vacuum Cleaner Robot," *IJSREM*, vol. 9, no. 4, pp. 1–9, 2025.

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