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Design & Fabrication of a Robotic Vacuum Cleaner

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Abstract

This study presents the design and implementation of a robotic vacuum cleaner integrating advanced components and control systems to improve efficiency and autonomy. The fabricated vacuum cleaner has an optimum design featuring a custom design base, suction chamber with a semi-closed impeller, and Brushless DC (BLDC) motor for optimized airflow and suction power. The optimum design of the fabricated vacuum cleaner features a custom base, suction chamber with semi closed impeller, and Brush-less DC motor with optimized air flow and suction power. For autonomous navigation and obstacle avoidance, ultrasonic and infrared sensors are incorporated with the Arduino nano based control unit. A servo tester is utilized to regulate impeller rotation, enhancing suction performance. The vacuum cleaner operates on rechargeable Li-Po and Li-ion batteries, ensuring prolonged usage and portability. Ultrasonic and infrared sensor integration provides safety measures. The robotic vacuum cleaner demonstrates significant capabilities in indoor cleaning tasks, effectively navigating though obstacles. The modular design allows easy maintenance and customization, facilitating future upgrades and enhancements such as smart mapping and remote-control system. Overall, the robotic vacuum cleaner project represents a significant advancement in automated cleaning technologies, embodying principles of efficiency, convenience and sustainability.

Keywords: Robovac, Centrifugal impeller, Arduino nano.

1. Introduction

The persistent battle against household dust has led to a technological marvel – robotic vacuum cleaner (robovac). These autonomous devices, unlike their traditional counterparts, operate independently, freeing us from the chore of manual cleaning. However, it has some limitations. While some models can automatically return to their docking station for recharging, others require manual intervention [1]. While routine maintenance tasks such as dustbin evacuation and brush cleaning are necessary, robotic vacuum cleaners nonetheless provide a practical and effective solution for the upkeep of clean floors. The development of robovac is an ongoing process, with researchers constantly striving to improve their capabilities. A project by Asafa (2019) demonstrates a low-cost robovac built with Arduino and ultrasonic sensors. This project highlights the potential for creating affordable cleaning solutions [2]. But, the robotic vacuum cleaner has limited suction power and short battery life. It has to be manually recharged once the battery depletes. Further research explores various aspects of robovac development, including noise reduction [3], low-cost navigation using the Internet of Things (IoT), smartphone app integration for control [4], and even waste segregation capabilities [5].

Suction power can be improved by using centrifugal fan with inclined blades for vacuum cleaner motor. (JURIJ PREZELJ) [7]. The impact of the impeller's triangular cross section on its aerodynamic characteristics and psychoacoustic performance. Compared to impellers with upright blades, those with slanted blades perform better in psychoacoustic measures. The impeller's efficiency frequently suffers when its noise level is reduced. These studies showcase the diverse approaches being explored to enhance robovac functionality.

2. Methodology

Vacuum Cleaning Process

A robotic vacuum cleaner is an autonomous cleaning tool that cleans floors on its own without the need for direct human assistance. Most of the robotic vacuum cleaners use rotating brushes and suction mechanisms to

lift dirt, dust, and debris from floors. In this project, negative pressure is generated using a BLDC motor & a semi-closed type of impeller. This causes an airflow which sucks dust, dirt & debris from the surface. The air flows through a nozzle & the dirt are separated into a separate chamber called a dust collector using a filter & the filtered air is released into the environment. This is considered the suction part of a robotic vacuum cleaner. Key elements of the suction part are,
Body – To support all the components & navigate through the cleaning surface.
BLDC motor & Impeller – The BLDC motor is a high-speed motor. This with a semi-closed type of impeller creates vacuum pressure.
Nozzle – to suck dust from the surface.
Dust Collector & Filter – A separate chamber for collecting the dust using a filter.

Designing a Robotic Vacuum Analysis

Key considerations shaped the design:
Size: The robot's low profile ensures access to hard-to-reach areas. The base of the designed robot vacuum cleaner is only 1 cm above the surface. Its height and diameter were carefully chosen for optimal navigation within the corridor.
Component Harmony: The size and power of each component, like the suction chamber and impeller, were determined based on the robot's overall size and cleaning needs. The fabricated robot vacuum cleaner was precisely maintained at a height of 13 cm which was estimated in the design phase. Careful attention was given to weight distribution to mitigate the risk of tipping, with strategic placement of sensors, batteries, and other components. Because of a greater weight concentration at the rear of the device, a ball caster was implemented at the back to enhance stability. SolidWorks software was used to design, and 3D print each component for a perfect fit as shown in Fig. 1.

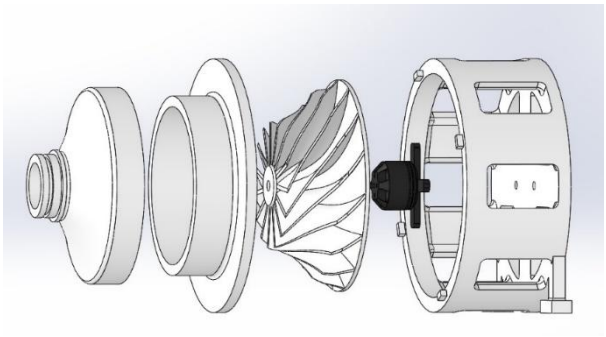


Fig. 1. Semi Closed Type Impeller

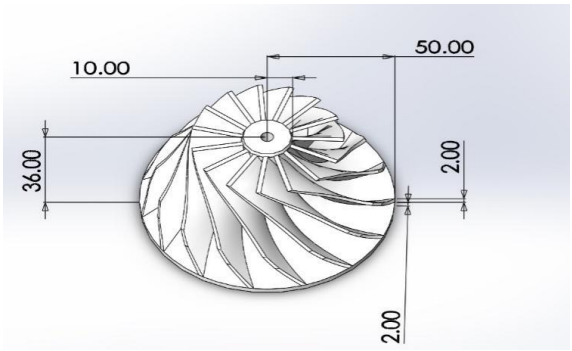
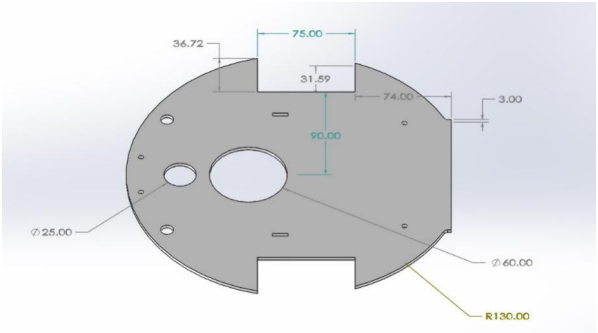


Fig. 2. Suction Chamber Components

As shown in Fig. 2, the impeller features a circular base with a diameter of 50 mm and a height of 36 mm. Centrifugal slanted blades, each with a thickness of 2 mm, are integrated to enhance suction efficiency. The casing is specifically designed to ensure effective suction and facilitate airflow circulation through various components, achieved through the strategic placement of an intentional gap within the suction chamber.
The Body's Role: The foundation(base) of the robot's body was designed to be lightweight yet structurally robust. This ensured that it could effectively house all components. The design emphasized cost-effectiveness



while allowing the efficient placement of batteries, sensors, and the dust collection system. The base, with a diameter of

Fig. 3. Base of Vacuum Cleaner

260 mm, was planned to accommodate the motor and wheels. Strategically positioned openings provided access for the dust collection system and the suction nozzle, as shown in Fig. 3.
A large central opening was incorporated to allow access to the dust collector and a smaller opening at the front enabled the intake of the suction nozzle. Additional openings in the base were included to enable the attachment of various components.

Mechanical Design of Robotic Vacuum Cleaner

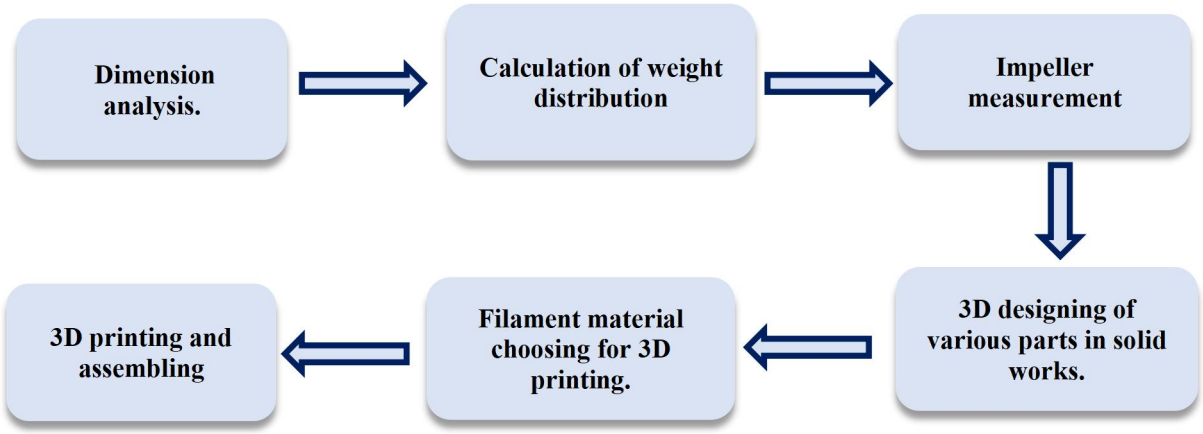


Fig. 4. Mechanical Design Flowchart

The design process shown in Fig. 4 consists of 6 steps. In the first step, the environment dimensions are determined where the robovac testing will take place. Secondly, the components like suction casing, impeller, and body dimension are analyzed according to the testing environment. Then all the parts are designed in Solid Works software. The weight distribution is kept in mind for proper balancing of the robot. After finalizing the design, all the parts are fabricated by a 3D printing process. Finally, all the parts are assembled.

Electrical System & Battery

Lithium-ion and LiPo batteries are used to power up the robovac. In this study an 1800 mAh-45C-11.1V-3S1P LiPo battery is used. It can supply 18 Amp current for 1 hour before discharging. It is used to power the BLDC motor for turning the impeller & create negative pressure [8]. The Li-Po battery was selected due to its ability to provide the high discharge rates required by the BLDC motor, making it more suitable compared to standard Li-ion batteries. Another set of Li-ion batteries is used to power control units. A Li-Po battery was not used to power the control unit because of its high discharge rate, which could damage the microcontroller (Arduino Nano). Therefore, a Li-ion battery was considered a more suitable choice for powering the control unit and enabling the movement of the robotic vacuum cleaner. A set of 3 Li-ion 3.7V batteries are used to power the microcontroller, motor driver & sensors.

Control Unit: Sensors & Microcontroller

A robotic vacuum consists of 2 integral parts, Suction part & Control unit. Arduino nano was used as the microcontroller with a breadboard, 1 ultrasonic sensor, 2 IR module, L298 motor driver, 2 wheels, 2 DC motor,

3 Li-ion batteries, 1 Li-po battery. Jumper wires are used to make the connection between the components. The sensors receive data from the testing environment & the microcontroller controls the robot's movement. The Arduino Nano was selected due to its small size, which enabled a more streamlined control unit. This compactness contributed to the reduction of the overall dimensions of the system, enhancing its ability to navigate efficiently through narrow openings. The Arduino Nano has a Mini-B USB connector and pin headers that make it simple to attach it to a breadboard. The eldest Arduino Nano board in the family is the classic Nano [9]. One of the best methods for accurately detecting levels and proximity is ultrasonic detection. Electronic devices that measure a target's distance are called ultrasonic sensors. They produce ultrasonic sound waves, which they then transform into electrical signals. Additionally, a transducer is present to send and receive ultrasonic pulses. These pulses aid in the transmission of data about nearby objects [10]. An IR receiver LED and additional parts for detecting and processing IR signals are found in an IR sensor module. Usually, it consists of a demodulator circuit, a signal amplifier, and an IR receiver LED. The signal amplifier and demodulator circuits are used to process and amplify the received signal, respectively, while the IR receiver LED is used to detect infrared signals. Remote control, motion detection, proximity sensing, and other electronic applications are just a few of the many uses for infrared sensor modules. They are frequently found in automation systems, robotics, and consumer electronics. [11]

3. Working Procedure

Firstly, an ESC (Electronic Speed Controller) is connected to the BLDC motor in one end & the other to a Li-Po battery terminal. A servo tester is also connected to the ESC to control the speed. The semi closed impeller is rigidly fitted in the BLDC motor. As the switch is turned on, the motor starts to turn with the impeller. While the impeller is turning, vacuum pressure is generated inside the suction chamber. The dust collector & nozzle are connected to the suction chamber. The vacuum pressure causes air to flow through the nozzle. The air carries dirt along with the flow & travels through the nozzle to dust collector. There exists a filter in the intersection of the suction chamber & dust collector. The filter separates the dirt from the air flow & dust is collected in the collector. The air flows through the filter to the suction chamber to the surroundings.

In the control unit the robot moves autonomously. The robot is equipped with 1 ultrasonic sensor & 2 IR sensors. The ultrasonic sensor detects objects in front of it by sending sound waves & calculating the time. The ultrasonic sensor has some limitations in detecting edges. So, an IR module is used to perfectly detect obstacles in front of the robot. Another IR sensor is used to prevent the robot from falling in a ditch. The robot normally moves on a plane surface but suddenly a ditch comes like stairs, this IR sensor will prevent the robot from falling. All these logics are coded in the microcontroller using the Arduino IDE software. The microcontroller Arduino Nano is powered by three Li-Ion batteries. The microcontroller receives data from the sensors & with the logics implemented on the microcontroller sends signal to the motor driver & controls the movement of the robot.

The components are connected in a sequence as described: Firstly, the power & ground pins of Arduino uno are connected to the power rails of the breadboard. Then the VCC pin of the ultrasonic sensor is connected to the 5V rail on the breadboard & GND pin to ground rail. Afterwards the trigger pin & echo pin of the ultrasonic sensor to are connected respectively to the uno digital pins 11 & 12. The VCC & GND of IR sensor are connected to 5V & GND respectively. Then, the output pins of the IR sensors are connected to uno digital pins 10 & 4 respectively. The 4 input pins of L298N are connected to digital pins of the nano 6,7,8,9 respectively. Next, the motor power supply is connected to the appropriate terminals of the L298N motor drive. Finally, the batteries are connected to the power input of the L298 motor driver to power the motors.

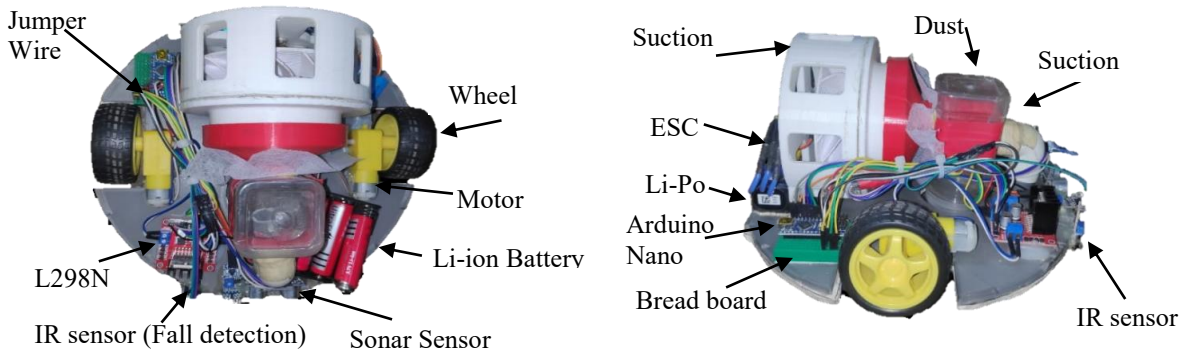


Fig. 5. Prototype of the Vacuum Cleaner

4. Result & Calculation

Suction Pressure

The measured suction pressure during the experiment represented only partial pressure. This is due to the 20 mm diameter of the suction pipe and the 10 mm diameter of the manometer tube inlet. Therefore, the recorded pressure does not reflect the true suction pressure, which is expected to be significantly higher. Suction Pressure was measured using a U-tube manometer in the. It was 15mm of H_2O. So, the partial suction pressure is,

$P = h\rho g$ [12]
$P = .015 \times 1000 \times 9.81\ Pa$
$P = 147.15\ Pa$
$P = 1.45 \times 10^{-3} atm$

Input Power of Suction

Input voltage V = 11.1 V
Input Current I = 1800Ma
= 1800/1000 = 1.8 amp
We know,
$P = VI$ [13]
$P = (11.1 \times 1.8)W$
$P = 20W$

Battery Calculation

$$Battery\ life\ (hrs) = Total\frac{Capacity(mAh)}{current\ consumption} \quad [14]$$

BLDC motor current discharge = 800 mA
Battery Life (hrs.) = (1800/800) × .7 = 1.5 hr.

5. Discussion

The prototype robotic vacuum cleaner is cheaper than most of the vacuum cleaners available in the market. It successfully performs cleaning while avoiding obstacles. Compared to other vacuum cleaners at has more compact design. A comparison is shown in Table.1 between prototype vacuum cleaner and MI robotic vacuum cleaner. The prototype has significantly lower suction pressure due to low powered motor. It has comparatively lower battery size and 1 IR sensor for stair mapping instead of 4 anti-drop sensors. As less sensors are used, the prototype has comparatively longer battery life despite of having 1800 mAh battery compared to the 2.5 hour battery life with 5200 mAh battery in MI robot vacuum cleaner.

Table. 1. Performance & Cost Comparison

Specification	Robotic Vacuum Cleaner	MI Robot Vacuum Cleaner
Image		
Dimension	Dia: 130 mm Height: 150 mm	Dia: 340 mm Height: 95 mm
Suction Pressure	147.15 Pa	1800 Pa
Motor	BLDC 1400 KV brushless motor	Nidec brushless Dc motor
Navigation	1 Ultrasonic & 1 IR module	Laser Distance Sensor (LDS), Simultaneous Localization and Mapping algorithm
Battery	1800 mAh	5200 mAh

Battery life	1.2 hr	2.5 hr
App Control	No App Control	Available with customized cleaning area
Stair drops Sensor	1 IR module	4 anti-drop stair sensors
Automatic Recharge System	Not Available	Available
Cost	8900	28,500

6. Conclusion

This project successfully built a working robotic vacuum cleaner equipped with obstacle avoidance and fall protection. The design incorporated a custom base, a suction chamber, and a semi-closed impeller for efficient dust collection. A BLDC motor powered by Li-ion batteries provided the driving force, with an ESC offering precise speed control. A servo tester played a crucial role in rotating the impeller within the chamber, generating the necessary vacuum pressure. Airflow directed through a nozzle dislodged dirt and debris, which was then collected in a dedicated dust bin.

For autonomous navigation, the robot relied on an Arduino Nano as its control unit. This microcontroller coordinated the movement and functionality of the entire system. Obstacle avoidance was achieved through the strategic placement of ultrasonic and infrared sensors. The ultrasonic sensor provided long-range detection, while the infrared sensors focused on immediate object proximity. An additional infrared sensor played a vital role in fall protection by detecting drops and preventing the robot from tumbling downstairs.

In conclusion, the robotic vacuum cleaner project represents a promising step towards the advancement of automated cleaning technologies, offering a versatile and effective solution for household and commercial cleaning applications.

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