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Autonomous Multi Surface Robotic Floor Cleaner

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Abstract - This paper presents the design and development of an advanced autonomous cleaning robot capable of performing efficient dry and wet cleaning operations in indoor environments. The system is built around the Arduino Mega microcontroller, which acts as the central processing unit for coordinating various subsystems including navigation, sensing, and cleaning mechanisms. The robot is equipped with ultrasonic and IR sensors for real-time obstacle detection and surface identification, enabling safe and intelligent movement across different floor types.

A key feature of the system is its dual-mode cleaning capability, which integrates a high-speed vacuum pump for dry dust collection and a motorized mopping unit for wet cleaning. The addition of dedicated rotating side brushes enhances edge and corner cleaning efficiency, addressing a common limitation in conventional cleaning robots. Furthermore, an optimized water dispersion system ensures uniform distribution of water during mopping, reducing wastage while maintaining effective cleaning performance.
The robot also incorporates a live video streaming module, allowing remote monitoring and control via a mobile or computer interface. Intelligent path planning algorithms are implemented to improve area coverage and minimize redundant movement, thereby increasing overall cleaning efficiency and reducing power consumption. The system is powered by a rechargeable battery, making it portable and suitable for continuous operation in residential as well as commercial environments such as offices, hospitals, and shopping complexes.
Compared to existing solutions, the proposed robot offers a balance between cost, performance, and functionality. Its modular design allows for easy maintenance and future upgrades. Overall, the developed system demonstrates a reliable, affordable, and scalable solution for automated cleaning, contributing to reduced human effort and improved hygiene standards in modern indoor spaces.

1. INTRODUCTION :

The global shift toward smart home automation has been accelerated by the need for consistent, labor-efficient cleaning solutions. Manual floor cleaning is not only time-consuming but often inconsistent in public spaces like hospitals, malls, and airports, where hygiene is paramount. While commercial products like the iRobot Roomba have popularized robotic cleaning, many existing budget models are restricted to residential dry vacuuming and lack robust navigation or wet-mopping capabilities.
This project attempts to overcome these challenges by proposing a modular hybrid system. By integrating a vacuum unit, rotating brushes, and a motorized mopping mechanism into a single intelligent framework, the robot provides a comprehensive "single-pass" cleaning cycle. The design prioritizes affordability and maintainability by utilizing off-the-shelf components, making advanced robotics accessible for a wider range of applications. In addition to its functional advantages, the proposed system also emphasizes scalability and customization. The modular framework allows future enhancements such as integration of advanced mapping algorithms, machine learning-based navigation, Internet of Things (IoT) connectivity, and cloud-based data analysis. These features can transform the robot into a fully intelligent cleaning system capable of adapting to dynamic environments and user requirements.

In conclusion, this project aims to bridge the gap between high-cost commercial cleaning robots and limited-functionality budget models by delivering a cost-effective, efficient, and multifunctional robotic cleaning solution. By integrating vacuuming, brushing, and mopping into a single automated platform, the system enhances cleaning performance while reducing human effort and operational time. The proposed approach not only contributes to the field of service robotics but also provides a practical and scalable

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solution for modern cleaning challenges in both residential and commercial environments.

2. SYSTEM ARCHITECTURE AND HARDWARE INTERFACING

The proposed autonomous cleaning robot is designed using a modular and scalable architecture, where multiple subsystems—namely mobility, cleaning, sensing, and control—operate in coordination to achieve efficient and intelligent cleaning. This modular design ensures flexibility, ease of maintenance, and future upgrade capability. Each subsystem performs a dedicated function while continuously exchanging data with the central controller, enabling real-time decision-making and adaptive behavior in dynamic environments.
The overall system is structured such that sensor inputs are processed by the central processing unit, which then generates appropriate control signals for actuators including motors, pumps, and cleaning mechanisms. This closed-loop system enhances reliability and allows the robot to respond effectively to environmental changes.

2.1 Central Processing Unit: AVR Atmega328P-u

At the core of the robot lies the AVR Atmega328P-u microcontroller board, which is based on the ATmega328P-u architecture. It serves as the brain of the system, coordinating all hardware components and executing control algorithms. The selection of this microcontroller is primarily due to its high number of input/output pins, which makes it suitable for handling multiple sensors and actuators simultaneously without requiring additional interfacing hardware such as multiplexers.
The AVR Atmega328P-u offers 54 digital I/O pins (of which 15 can be used for PWM output), 16 analog input channels, and multiple serial communication ports. These features allow seamless integration of sensors, motor drivers, and communication modules, making it ideal for complex embedded applications like autonomous robots.

Logic Execution:

The microcontroller performs continuous real-time sensor polling and processes incoming data to determine the robot's operating conditions. Based on this data, it generates Pulse Width Modulation (PWM) signals to control motor speed and direction through motor drivers. Additionally, it manages the activation and coordination of cleaning modules such as the vacuum pump, rotating brushes, and mopping system. Decision-making algorithms implemented in the controller enable obstacle avoidance, path correction, and efficient cleaning patterns.

Firmware Development:

The system firmware is developed using Embedded C within the Arduino IDE environment. The software is structured in a modular format, separating functionalities such as sensor handling, motor control, and cleaning operations into independent code blocks. This modular programming approach simplifies debugging, enhances readability, and allows easy integration of additional features such as IoT connectivity or advanced navigation algorithms in future iterations.

2.2 Perception Suite: Sensors and Navigation

To achieve safe, autonomous, and efficient navigation, the robot employs a comprehensive perception system consisting of multiple sensors. A dual-sensor strategy combining ultrasonic and infrared sensing technologies is implemented to provide reliable environmental awareness and surface detection.

Ultrasonic Sensors (HC-SR04):

The robot is equipped with three ultrasonic sensors strategically positioned around its chassis—Front, Front-Left, Front-Right, Middle —to achieve near-omnidirectional obstacle detection. These sensors operate based on the time-of-flight principle, where ultrasonic waves are emitted and the time taken for the reflected signal to return is measured. This time is then converted into distance, allowing the robot to detect obstacles in its vicinity.
The system continuously monitors distances from all directions and compares them with a predefined safety threshold (typically around 20 cm). If an obstacle is detected within this range, the controller immediately initiates corrective actions such as stopping, turning, or rerouting the robot's path. This ensures collision avoidance and smooth navigation even in cluttered environments.

Infrared (IR) Sensors:

In addition to ultrasonic sensors, four infrared (IR) sensors are mounted on the underside of the robot. These sensors primarily perform cliff detection by measuring the reflectivity of the surface beneath the robot. If a sudden drop in reflectivity is detected—indicating the absence of a surface such as stairs or ledges—the controller halts movement to prevent accidental falls.
Furthermore, IR sensors are utilized for basic surface classification. By analyzing the intensity of reflected infrared light, the system can differentiate between high-reflectivity surfaces (such as tiles or marble) and low-reflectivity surfaces (such as carpets or rough flooring). This information is used to intelligently control the mopping mechanism—for example, disabling water-based cleaning on carpets to prevent damage and enabling it on hard surfaces for effective cleaning.

This integrated perception system significantly enhances the robot's autonomy by enabling it to make informed decisions based on real-time environmental feedback. The combination of ultrasonic and infrared sensing ensures both obstacle avoidance and surface safety, making the system robust and reliable for practical applications.

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3. HYBRID CLEANING MECHANISM

The effectiveness of the proposed autonomous cleaning robot is primarily attributed to its hybrid cleaning mechanism, which integrates multiple cleaning techniques into a single unified system. Unlike conventional robotic cleaners that rely on a single cleaning method, this design combines vacuum suction, mechanical agitation, and wet mopping to achieve superior cleaning performance across a variety of surfaces. The integration of these modules enables the robot to perform a comprehensive "single-pass" cleaning operation, thereby reducing cleaning time and improving overall efficiency.

The hybrid mechanism is carefully designed to ensure coordination between different subsystems, preventing interference and maximizing cleaning effectiveness. Each module is optimized for a specific type of dirt or surface condition, and their operation is intelligently managed through embedded control logic.

3.1 Vacuum Suction and Surface Agitation

The first stage of the cleaning process focuses on the removal of dry debris such as dust, dirt particles, and hair. This is achieved through a combination of suction and mechanical agitation.

Suction Motor:

A compact, high-speed suction motor (miniature vacuum pump) is used to generate a partial vacuum within the debris collection chamber. This pressure difference creates a strong airflow that pulls in loose particles from the floor surface. The collected debris is stored in a detachable and easy-to-clean container, enhancing user convenience and maintenance.

The suction system is designed to balance power consumption and efficiency, ensuring adequate cleaning performance without excessive energy usage. Proper sealing and airflow channel design are also considered to minimize losses and maximize suction effectiveness.

3.2 Motorized Mopping and Water Management

The second stage of the cleaning process involves wet cleaning, which is essential for removing fine dust, stains, and sticky residues that cannot be eliminated through dry cleaning alone.

Mop Unit:

The robot is equipped with a rotating microfiber mop pad mounted underneath the chassis. This pad is driven by a low-speed DC motor, providing a gentle yet effective scrubbing action. Microfiber material is chosen due to its high absorbency and ability to trap fine particles, ensuring efficient cleaning without damaging the floor surface.

The controlled rotational movement of the mop ensures uniform cleaning and prevents excessive friction, making it suitable for delicate surfaces such as tiles, marble, and wooden flooring.

Water Dispersion System:

An intelligent water management system is implemented to regulate the flow of water during the mopping process. A small onboard reservoir stores the cleaning liquid, which is released through a solenoid valve. The valve is electronically controlled by the microcontroller via a relay module.

The system operates on a timed control mechanism, where water is dispensed in controlled intervals rather than continuously. This prevents over-wetting of the surface, avoids puddle formation, and ensures efficient utilization of water. Additionally, the system can adapt water usage based on surface type, further enhancing its effectiveness and safety.

3.3 Sequential Operation Logic

A critical aspect of the hybrid cleaning system is the implementation of intelligent sequential operation logic. Since combining dry and wet cleaning processes simultaneously can lead to the formation of sludge or inefficient cleaning, the system is programmed to execute tasks in a specific order.

Initially, the vacuum suction and brush modules are activated to remove loose dust, dirt, and debris from the surface. Only after the dry cleaning phase is completed does the system activate the mopping mechanism. This ensures that the mop operates on a relatively clean surface, allowing it to focus on removing stains and fine particles.

Furthermore, the activation of the mopping system is conditioned on surface detection data obtained from sensors. For example, wet mopping is disabled on carpeted or low-reflectivity surfaces to prevent damage. This decision-making process enhances both cleaning efficiency and operational safety.

The sequential logic not only improves cleaning performance but also optimizes power consumption by ensuring that only the required modules are active at any given time. This contributes to longer battery life and more efficient operation of the robot.

Overall, the hybrid cleaning mechanism represents a significant advancement over conventional single-function cleaning robots by providing a comprehensive, efficient, and intelligent cleaning solution adaptable to multiple surface types and environmental conditions.

4. MOBILITY AND DRIVE SYSTEM

The mobility system of the autonomous cleaning robot is a critical subsystem responsible for movement, navigation, and area coverage. It is designed to provide stability, maneuverability, and precise control, enabling the robot to operate efficiently in both open and cluttered indoor environments. The system integrates mechanical design with electronic control to achieve smooth and responsive motion.

4.1 Drive Configuration

The robot employs a four-wheel differential drive configuration, which is widely used in mobile robotics due to its simplicity, robustness, and high maneuverability. In this setup, the wheels on each side of the robot are driven

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independently, allowing the system to control motion by varying the speed and direction of motors on either side.
This configuration enables multiple types of movement, including:

- **Linear Motion:** Achieved when all wheels rotate in the same direction at equal speed, allowing the robot to move forward or backward.
- **Turning Motion:** By reducing or stopping the speed of wheels on one side while maintaining motion on the other, the robot can execute smooth turns.
- **In-Place Rotation (Zero Turning Radius):** When wheels on one side rotate forward and the opposite side rotates backward, the robot can rotate about its own axis. This feature is particularly useful in confined spaces and for precise navigation.

The four-wheel design also improves stability and load distribution, which is essential for supporting additional components such as the cleaning modules, water reservoir, and battery pack. This ensures consistent traction and reduces the risk of slippage during operation.

4.2 Motor Drivers: L298N Dual H-Bridge Motor Driver

To control the movement of the DC motors, the robot uses two L298N Dual H-Bridge Motor Driver modules. Each driver is capable of controlling two motors, allowing independent control of all four wheels.
The L298N driver operates on the H-bridge principle, enabling:

- **Bidirectional Control:** Motors can rotate in both forward and reverse directions.
- **Speed Control:** Pulse Width Modulation (PWM) signals from the microcontroller regulate motor speed.
- **Braking Functionality:** The driver can quickly stop motors when required, enhancing control and safety.

The motor drivers act as an interface between the low-power control signals from the microcontroller and the higher power requirements of the DC motors. This ensures that the control unit can safely and effectively manage motor operations without being directly exposed to high current loads.

4.3 Signal Integrity and Power Isolation

Maintaining signal integrity is crucial for reliable system performance, especially in embedded systems where both high-power and low-power components operate simultaneously. DC motors and drivers can introduce electrical noise and electromagnetic interference (EMI), which may disrupt the functioning of sensitive components such as the microcontroller and sensors.
To address this, the system implements **power isolation techniques**, where the motor drivers are powered through a separate supply line from the logic circuits (microcontroller and sensors). This separation minimizes noise coupling and ensures stable operation of control signals.
Additional measures include:

- Use of common grounding to maintain a reference potential across all components
- Decoupling capacitors to filter voltage fluctuations and noise
- Proper wiring and layout practices to reduce interference

These design considerations significantly enhance system reliability, prevent unintended behavior, and ensure accurate signal transmission throughout the robot.

5. CONNECTIVITY AND MANUAL OVERRIDE

To enhance user interaction, monitoring, and operational flexibility, the proposed cleaning robot incorporates a wireless communication system with manual override capabilities. While the robot is primarily designed for autonomous operation, this feature allows users to remotely monitor and control the robot when necessary. This is particularly useful during testing, maintenance, or operation in complex environments where human intervention may be required.
The connectivity system is designed to be cost-effective, responsive, and easy to use, ensuring seamless communication between the user and the robot without requiring specialized hardware or software.

5.1 Implementation:

The RASBERI PI CAM module serves as the central component for wireless communication and real-time visual monitoring. It is a compact and powerful microcontroller with built-in Wi-Fi capability and an integrated camera, making it ideal for IoT-based robotic applications.
The RASBERI PI CAM is configured to operate as a local web server, allowing it to host a web interface that can be accessed through any standard web browser on a smartphone, tablet, or computer. Once connected to the same network, the user can interact with the robot without the need for dedicated mobile applications.
Live Video Streaming:
One of the key features of the RASBERI PI CAM is its ability to stream real-time video at approximately 20–25 frames per second (fps). This live feed provides continuous visual feedback of the robot's surroundings, enabling users to monitor its movement and cleaning performance remotely. This is especially beneficial in large or obstructed environments where direct line-of-sight is not possible.

User Interface (UI):

The module hosts a simple and intuitive web-based user interface that includes:
Directional control buttons (Forward, Backward, Left, Right, Stop)
Cleaning function toggles (Vacuum ON/OFF, Mop ON/OFF)
Real-time video display window
This interface allows users to manually override the autonomous system and take direct control of the robot whenever needed. The simplicity of the UI ensures that even non-technical users can operate the system effectively.

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5.2 UART Communication Link

To establish communication between the wireless module and the main controller, a Universal Asynchronous Receiver-Transmitter (UART) protocol is implemented between the RASBERI PI CAM and the AVR Atmega328P-u.

Command Transmission:

When a user interacts with the web interface, the RASBERI PI CAM processes the input and converts it into predefined command signals. These commands are then transmitted to the Arduino Mega via the UART serial communication interface.

Real-Time Execution:

Upon receiving the commands, the Arduino Mega immediately processes them and executes the corresponding actions, such as controlling motor movement or activating cleaning modules. This ensures minimal latency between user input and robot response, providing a smooth and responsive control experience.

System Coordination:

The separation of communication (RASBERI PI -CAM) and control (Arduino Mega) tasks improves overall system efficiency and reliability. While the RASBERI PI handles networking and video streaming, the Arduino focuses on real-time hardware control and sensor processing. This distributed architecture reduces the computational load on individual components and enhances system performance.

6. BLOCK DIAGRAM:

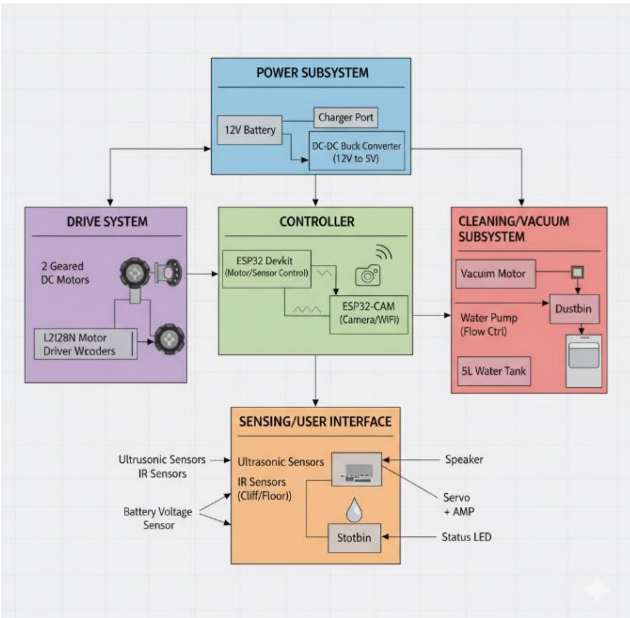

Fig. 1

7. CIRCUIT DIAGRAM:

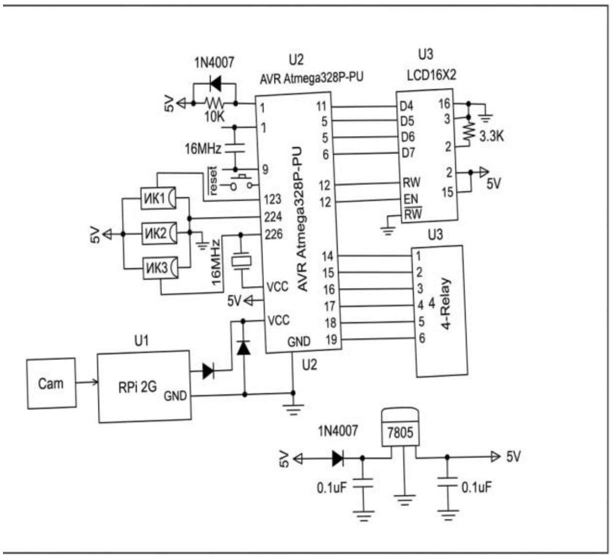

Fig.2

8. EXPERIMENTAL RESULTS AND PERFORMANCE ANALYSIS

To evaluate the effectiveness and reliability of the proposed autonomous cleaning robot, a series of experimental tests were conducted under different environmental conditions. The testing environments included tiled floors, wooden surfaces, and cluttered indoor spaces to simulate real-world scenarios. The primary objective of these tests was to assess the robot's performance in terms of area coverage, obstacle detection, cleaning efficiency, and operational safety.
The experiments were carried out in both controlled and semi-structured environments to ensure consistency and repeatability of results. Performance metrics were recorded and analyzed to determine the system's practical applicability and efficiency.

8.1 Area Coverage Analysis

The robot demonstrated an average **area coverage efficiency of approximately 95%** in controlled environments. This indicates that the majority of the accessible floor space was successfully cleaned during operation.
The high coverage rate can be attributed to:

- The differential drive mechanism enabling flexible movement
- Effective obstacle avoidance strategies
- Systematic navigation patterns implemented in the control algorithm

However, minor uncleaned regions were observed near corners and tightly confined spaces, which is a common limitation in most autonomous cleaning systems.

8.2 Obstacle Detection and Navigation Performance

The ultrasonic sensor array performed reliably in detecting obstacles of varying sizes and shapes. The system was

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capable of identifying objects as small as **3 cm in size**, with an average measurement error of less than **5 cm**.
Key observations include:

- Accurate distance estimation in open and moderately cluttered environments
- Real-time path correction when obstacles were detected within the predefined threshold (20 cm)
- Smooth navigation with minimal collisions

The multi-directional sensor placement significantly enhanced environmental awareness, enabling the robot to operate safely and efficiently.

8.3 Cleaning Efficiency Evaluation

The cleaning performance of the robot was evaluated by measuring the amount of debris collected in a single cleaning cycle. Experimental results showed that the system was able to collect approximately **85% of dry debris** in a single pass.
This efficiency is achieved through:

- The combined action of rotating brushes and suction mechanism
- Proper alignment of brush and vacuum intake
- Sequential cleaning logic ensuring effective debris removal before mopping

The wet mopping system further improved overall cleanliness by removing fine dust particles and stains that remained after dry cleaning.

8.4 Safety and Reliability Assessment

Safety is a critical factor in autonomous systems, particularly when operating near stairs or elevated surfaces. The IR-based cliff detection system demonstrated a **100% success rate** in all test scenarios.
During testing:

- The robot successfully detected edges and avoided falling from stairs
- Immediate stopping action was triggered upon detection of surface discontinuity
- No failure cases were observed in repeated trials

This highlights the robustness and reliability of the safety subsystem.

8.5 Identified Limitations

Despite its strong performance, certain limitations were identified during testing:

1. Navigation Delays in Complex Environments:

In highly cluttered spaces, the robot occasionally experienced slight delays in path recalculation. This is primarily due to the increased processing required for handling multiple obstacle inputs simultaneously. While the delays were minimal, they may affect efficiency in densely populated environments.

2.Sensor Sensitivity Constraints:

The system showed limited ability to detect very small or low-profile obstacles (below 1.5 cm in height). Such objects may fall outside the effective detection range of ultrasonic sensors, leading to occasional missed detections.

3.Corner and Edge Cleaning:
Like many robotic cleaners, the robot faced minor challenges in cleaning sharp corners and edges due to physical design constraints.

8.6 Overall Performance Summary

The experimental results demonstrate that the proposed system is:

- Highly efficient in area coverage and cleaning performance
- Reliable in obstacle detection and safety mechanisms
- Capable of operating effectively across multiple surface types

While some limitations exist, they can be addressed in future improvements through enhanced algorithms, advanced sensors (such as LiDAR or vision-based systems), and design optimization.

9. Prototype Model :

Fig.3

9.1 Model View :

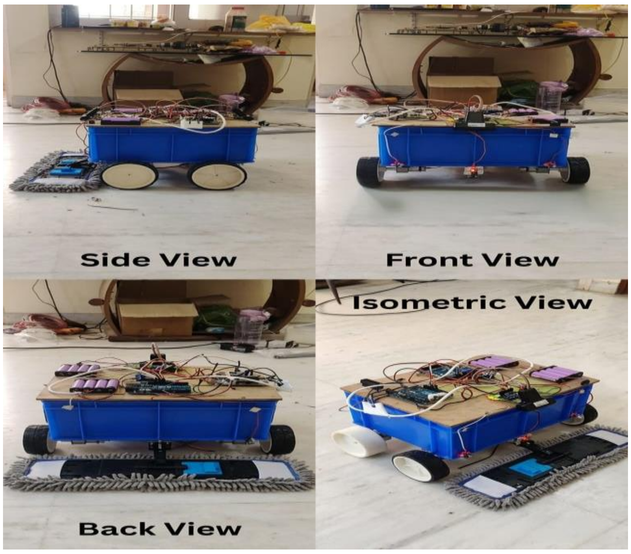

Fig.4

10. CONCLUSION AND FUTURE SCOPE

The proposed autonomous cleaning robot demonstrates a successful integration of multiple subsystems, including sensing, mobility, vacuum cleaning, and wet mopping, into a unified and modular framework. The system effectively addresses the limitations of conventional cleaning methods by providing a comprehensive "single-pass" solution capable of handling both dry and wet cleaning tasks. Its modular architecture ensures flexibility, ease of maintenance, and scalability, making it suitable for a wide range of applications, from residential use to semi-commercial environments.

The implementation of a hybrid control strategy, combining autonomous operation with manual override through the RASBERI PI-CAM interface, significantly enhances user interaction and operational control. Real-time video streaming and web-based control allow users to monitor and guide the robot when necessary, improving reliability and usability compared to traditional budget robotic cleaners. Experimental results validate the system's effectiveness, showing high area coverage, reliable obstacle detection, and strong cleaning performance, along with robust safety features such as cliff detection.

Furthermore, the use of cost-effective, off-the-shelf components such as the AVR ATMega 328P-U ensures that the system remains affordable without compromising functionality. This makes the proposed design a practical and accessible solution for modern cleaning challenges, particularly in environments where efficiency, hygiene, and automation are critical.

10.1 Future Scope

Although the current system performs efficiently, there are several opportunities for enhancement to further improve intelligence, autonomy, and performance:

1. LIDAR Integration and Advanced Navigation:

Future development can include the integration of Light Detection and Ranging (LiDAR) sensors to enable advanced mapping and navigation capabilities. By implementing Simultaneous Localization and Mapping (SLAM) algorithms, the robot will be able to create real-time maps of its environment, optimize cleaning paths, and avoid redundant coverage. This will significantly improve efficiency in large and complex spaces.

2. Machine Learning-Based Cleaning Optimization:

Incorporating machine learning techniques can enhance the robot's decision-making capabilities. By training models to recognize different levels and types of dirt, the system can dynamically adjust parameters such as suction power, brush speed, and water usage. This adaptive behavior will lead to improved energy efficiency and more effective cleaning performance.

3. IoT and Cloud Integration:

Future versions of the system can be integrated with IoT platforms, allowing users to monitor performance data, schedule cleaning tasks, and control the robot remotely via cloud-based applications. Data analytics can also be used to optimize cleaning patterns over time.

4. Improved Sensor Suite:

Upgrading to advanced sensors such as vision-based cameras or depth sensors can improve obstacle detection accuracy, especially for low-height or transparent objects that are difficult to detect using ultrasonic sensors.

In conclusion, the proposed system provides a strong foundation for the development of intelligent, cost-effective cleaning robots. With further advancements in navigation, artificial intelligence, and automation, the system can evolve into a fully autonomous and smart cleaning solution capable of meeting the demands of modern smart environments.

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