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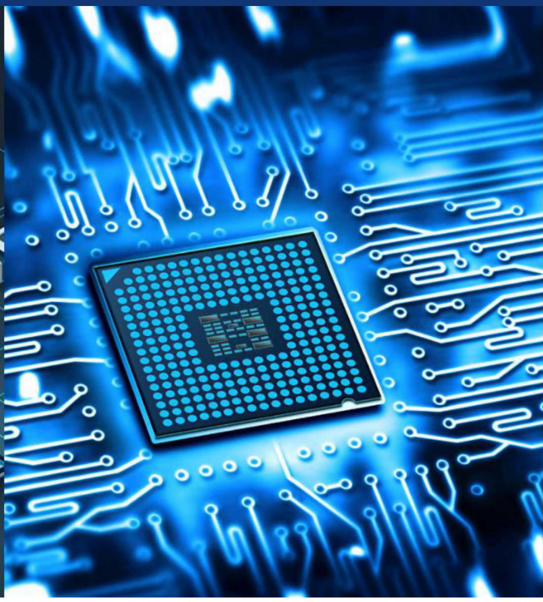

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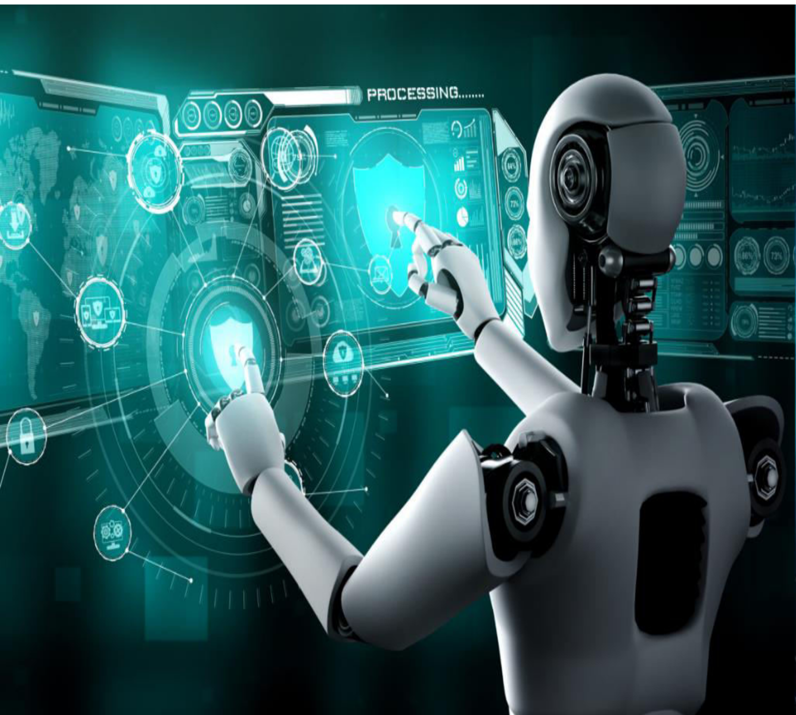

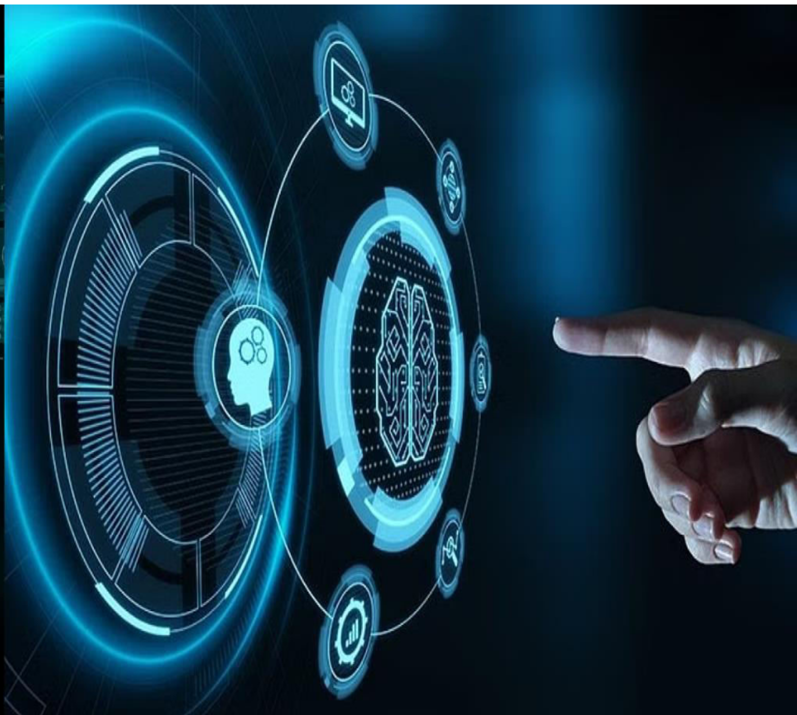

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Eco-Friendly Automatic Car Washing Robot

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ABSTRACT: Conventional car washing uses 120-150 liters of water per vehicle and requires high manual effort, causing inefficiency and environmental damage. This work presents an eco-friendly automatic car washing robot that improves efficiency through automation and resource optimization. The system performs spraying, soap application, brushing, rinsing, and drying using a microcontroller-based control system. A water recycling unit filters and reuses wastewater, achieving about 70-80% reuse and reducing consumption. Biodegradable detergents further lower chemical impact. The system follows a predefined sequence with controlled actuators for proper positioning and uniform cleaning. It reduces cleaning time to 25-30 seconds, lowers water usage, and ensures consistent performance, offering a sustainable and scalable solution for urban vehicle cleaning. Overall, it enhances reliability and operational efficiency significantly.

KEYWORDS: Automatic Car Wash, Water Recycling, Eco-Friendly System, Automation, Microcontroller

I. INTRODUCTION

The rapid increase in vehicle ownership has led to a growing demand for efficient and sustainable car washing systems. Conventional car washing methods consume large quantities of water and rely heavily on manual labor, resulting in inconsistent cleaning quality and inefficient operation. Typically, 120–150 liters of water is used per vehicle, contributing to significant water wastage, especially in urban areas facing water scarcity. In addition, the use of chemical detergents leads to environmental pollution through untreated wastewater discharge, which negatively affects soil and water quality.

To address these challenges, this paper presents an Eco-Friendly Automatic Car Washing Robot designed to automate the cleaning process while minimizing water usage and environmental impact. The system integrates a microcontroller-based control unit to manage multiple cleaning stages, including spraying, soap application, brushing, rinsing, and drying. A water recycling mechanism is implemented using filtration techniques such as mesh, sand, and activated carbon, enabling reuse of wastewater and improving overall efficiency.

The proposed system also focuses on reducing operational time and improving reliability by eliminating human dependency. By using controlled water flow and automated sequencing, the system ensures optimal utilization of resources without compromising cleaning performance. This system contributes toward sustainable growth by reducing resource consumption, minimizing environmental impact, and promoting eco-friendly vehicle maintenance practices in both domestic and commercial applications.

II. LITERATURE SURVEY

In recent years, significant research has been carried out in the areas of water conservation, automated cleaning systems, and eco-friendly technologies. Conventional car washing systems have been widely studied for their high-water consumption, typically ranging between 120–150 liters per vehicle. Studies have shown that the integration of water recycling systems using multi-stage filtration can reduce water usage by up to 70–80%, making them more sustainable and environmentally friendly.

Automation in cleaning systems has also gained attention, where robotic and sensor-based technologies are used to improve efficiency and consistency. Automated systems reduce human effort and provide uniform cleaning results

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compared to manual methods. Additionally, the use of biodegradable cleaning agents has been explored to minimize the harmful effects of chemical runoff on the environment.

Recent advancements have focused on developing integrated systems that combine automation with water management techniques. Some studies highlight the use of conveyor-based mechanisms and programmable controllers to optimize washing cycles and reduce operational time. However, many existing solutions are either expensive or lack efficient recycling mechanisms, limiting their practical implementation.

Therefore, there is a need for a compact, cost-effective, and fully integrated system that combines automation with efficient water recycling. The proposed system addresses this gap by providing a balanced solution that ensures sustainability, efficiency, and practical usability in real-world conditions.

III. METHODOLOGY & MATERIALS

A) System Design
The proposed system is designed as a microcontroller-based automated car washing robot that integrates mechanical, electrical, and control components. The system operates in a predefined sequential manner to achieve efficient and consistent vehicle cleaning. The design focuses on simplicity, cost-effectiveness, and ease of implementation for small-scale applications.

B) Components and Setup
The system consists of key components such as a microcontroller unit, water pump, soap dispenser pump, DC gear motors for brush movement, relay module for switching operations, and a blower for drying. These components are interconnected through control circuitry to enable automated operation. The conveyor mechanism is used to move the vehicle through different cleaning stages in a controlled manner.

C) Working Process
The washing process is carried out in multiple stages. Initially, the vehicle is positioned manually on the conveyor platform. The process begins with water spraying to remove loose dirt, followed by soap application using a pump. Rotating brushes driven by DC motors perform scrubbing of the vehicle surface. After scrubbing, rinsing is carried out using clean or recycled water to remove soap and remaining dirt. Finally, a blower is used to dry the vehicle surface. The entire process follows a fixed sequence controlled by the microcontroller.

D) Water Recycling System
To improve sustainability, the system includes a water recycling mechanism. Used water is collected in a storage tank and passed through multiple filtration stages such as mesh filtration for large particles, sand filtration for finer impurities, and activated carbon filtration for removing contaminants and odor. The filtered water is then reused for subsequent washing cycles, significantly reducing overall water consumption.

E) Control Mechanism
All operations are controlled by the microcontroller using predefined programming logic. The system ensures proper sequencing and timing of each stage using relay-based switching. This fixed control mechanism enables reliable and repeatable operation without the need for complex sensing systems.

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Fig. 3.1: Automated Car Washing System Showing Spraying and Brushing Stages

IV. HARDWARE IMPLEMENATION

The proposed Eco-Friendly Automatic Car Washing Robot is developed using the following components for automation, cleaning, water recycling, and structural support:

1. Arduino Microcontroller: Acts as the central processing and control unit of the system. It executes the programmed sequence and controls all devices such as pumps, motors, and blower according to the washing cycle.
2. Relay Module: Functions as an interface between the low-power controller and high-power electrical devices. It enables safe switching of pumps, motors, and other loads automatically.
3. DC Water Pump: Used to deliver pressurized water during the pre-wash, spraying, and rinsing stages. It ensures continuous water flow for effective removal of dust and soap residues.
4. Soap Dispenser Pump: Supplies biodegradable detergent in controlled quantity during the washing process. Proper soap distribution improves cleaning quality and reduces chemical wastage.
5. DC Gear Motors: Used to rotate cleaning brushes at suitable speed with higher torque. These motors help in removing dirt, mud, and sticky contaminants from the vehicle surface.
6. Servo Motors: Used where controlled angular motion is required, such as nozzle adjustment or movement of selected mechanical parts. They provide better positioning accuracy.
7. Blower/Fan Unit: Installed in the final stage to remove water droplets from the vehicle surface. This improves drying efficiency and reduces manual wiping.
8. Conveyor Belt Mechanism: Moves the vehicle through different stages of washing in a smooth and controlled manner. It reduces manual handling and improves operational efficiency.
9. Rotating Brushes: Perform the main scrubbing action on the outer body of the vehicle. Soft brush material is preferred to avoid scratches while ensuring effective cleaning.
10. Supporting Frame Structure: Provides mechanical strength and holds all components such as motors, pumps, tanks, and conveyor assembly securely in position.
11. Water Collection Tank: Collects wastewater generated during the washing process for filtration and recycling purposes.
12. Connecting Wires and Cables: Used for power supply and signal transmission between electronic components.
13. Clamps, Nuts, Bolts, Bearings, and Fasteners: Used for assembly, alignment, rotational support, and structural stability of the complete system.

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V. SYSTEM BLOCK DIAGRAM

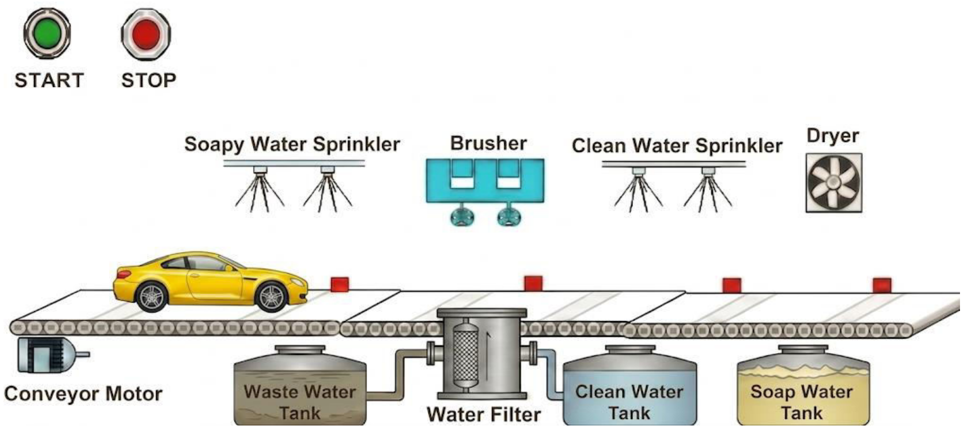

Fig. 4.1: Block Diagram of Automated Car Washing System with Water Recycling

Fig. 4.2: Flowchart of Automatic Car Washing Process

A. Block Diagram and Working

The system block diagram represents the overall operation of the Eco-Friendly Automatic Car Washing Robot. The process begins when the vehicle enters the conveyor-based washing platform and the system is activated. The conveyor motor moves the vehicle through different stages of cleaning in a sequential manner.

Initially, the vehicle passes through the soapy water sprinkler section, where eco-friendly detergent is sprayed uniformly over the surface. This is followed by the brushing stage, where rotating brushes driven by motors remove dirt and impurities from the vehicle body. After scrubbing, the vehicle moves to the clean water sprinkler section, where fresh or filtered water is used to rinse off the soap and remaining dirt.

In the final stage, a blower or dryer is used to remove excess water from the vehicle surface, completing the cleaning process. Once the washing cycle is finished, the vehicle exits the system. The system ensures smooth operation through controlled timing of each stage, maintaining efficiency and consistency throughout the process.

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VI. MATHEMATICAL MODELING AND CONTROL STRATEGY

The Eco-Friendly Automatic Car Washing Robot is modeled as a discrete-time sequential automation system controlled by an Arduino microcontroller. The complete washing cycle is executed through timed activation of pumps, motors, relays, and servo actuators. Mathematical modeling is used to define actuator timing, servo positioning, motor sequencing, and total process duration for reliable automatic operation.

A. Timed Sequential Operation Model
The washing process is divided into multiple stages executed in sequence:

- Water Spray Stage
- Brush Positioning Stage
- Motor Cleaning Stage 1
- Secondary Brush Stage
- Motor Cleaning Stage 2
- Rinsing Stage
- Drying Stage

The total cycle time is:
$T=\sum_{i=1}^{n} t_i$
where (t_i) represents the operating time of each stage.
Based on programmed delays:

- Pump spray = 3 s
- Motor 1 cleaning = 5 s
- Motor 2 cleaning = 5 s
- Relay 2 rinse = 4 s
- Relay 3 drying = 6 s

Thus, the total cycle is approximately 25 to 30 seconds excluding transition delays.
Why this model is used:
Timed control ensures repeatable operation without requiring complex sensors or feedback systems.
B. Servo Position Control Model
The angular movement of servo motors is represented as:
$\theta(t)=\theta_0+\omega t$
where ($\theta(t)$) is servo angle, (θ_0) is initial angle, and (ω) is angular speed.
Servo 1 and Servo 2 operate in opposite directions:
$\theta_2=90-\theta_1$
This synchronized motion enables balanced brush positioning on both sides of the vehicle.
Why this model is used:
Opposite servo movement improves surface contact symmetry and ensures uniform cleaning.
C. DC Motor Drive Model
The rotational speed of brush motors is given by:
$\omega=\frac{2\pi N}{60}$
where (N) is motor speed in RPM.
Motor torque is:
$T=Fr$
where (F) is cleaning force and (r) is brush radius.
Why this model is used:
Adequate speed and torque are necessary for removing dirt while avoiding excessive mechanical load.
D. Relay-Based Switching Logic
The actuator command is defined as:
[
U=
\begin{cases}
1, & \text{Relay ON / Device Active} \

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0, & \text{Relay OFF / Device Inactive}
\end{cases}
]
The Arduino controls relays for pump, rinse system, and drying system according to programmed timing.
Why this strategy is used:
Relay switching offers simple, reliable, and low-cost control of high-power devices.
E. One-Cycle Safety Logic
After completion of the washing sequence:
[
System = Stop
]
The controller enters a hold state until reset.
Why this logic is used:
This prevents unintended repeated cycles, saves power, and increases operational safety.
Overall Justification of Modeling Approach
The selected timed-control and actuator models provide a practical automation framework for the prototype. The strategy is:

- Computationally lightweight
- Easy to implement on Arduino
- Reliable for fixed-cycle operation
- Low cost and maintenance friendly
- Suitable for future sensor integration

This modeling approach ensures stable system performance, coordinated washing stages, and efficient automatic vehicle cleaning.

VII. RESULTS AND OBSERVATIONS

Experimental validation of the Eco-Friendly Automatic Car Washing Robot was carried out under controlled operating conditions to evaluate cleaning efficiency, water conservation, actuator performance, and overall system reliability. The prototype was tested using sequential washing cycles on vehicle surfaces with dust and light mud contamination.

A. Processing and Control Performance
The Arduino-based controller successfully executed the programmed washing sequence involving pumps, motors, relays, and servo actuators. All stages operated according to predefined timing without interruption.
Performance observations include:

- Stable relay switching for pump, rinse, and drying units
- Accurate sequential activation of all stages
- No controller reset during complete operation
- Reliable one-cycle automation process

The control strategy demonstrated dependable operation with low computational complexity.

B. Cleaning Performance Evaluation
The washing system was tested on dusty vehicle surfaces to observe cleaning effectiveness of spraying, brushing, and rinsing stages.
Observations include:

- Effective removal of loose dust after water spray stage
- Improved surface cleaning after rotating brush operation
- Reduced residual dirt after rinsing stage

The combination of mechanical brushing and controlled water flow improved cleaning consistency compared with manual washing.

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C. Water Recycling Performance

The wastewater generated during operation was collected and passed through mesh, sand, and activated carbon filtration stages.

Observed results include:

- Removal of visible suspended particles
- Improved water clarity after filtration
- Estimated water reuse efficiency of 70–80%

This confirms that the recycling unit significantly reduces fresh water consumption.

D. Drying and Final Output Performance

The blower unit was tested after the rinsing stage to remove remaining surface water.

Observations include:

- Noticeable reduction of water droplets
- Faster drying compared with natural air drying
- Improved final appearance of washed surface

The drying stage reduced the need for manual wiping after washing.

The structural frame remained stable throughout operation.

Fig. 8.1: Implemented Hardware Prototype of Eco-friendly Automatic Car Washing Robot

F. Overall System Observation

The complete prototype demonstrated efficient automatic washing with reduced manual effort, lower water usage, and repeatable cleaning performance. No major operational faults were observed during testing. The system proved to be suitable for small-scale domestic and commercial vehicle washing applications.

VIII. ADVANTAGES

Water Conservation: The integrated filtration and recycling system allows reuse of water, significantly reducing fresh water consumption.

- Eco-Friendly Operation: Use of biodegradable cleaning agents minimizes environmental pollution caused by chemical detergents.
- Reduced Manual Effort: Automatic operation decreases human labor requirement and reduces physical effort.
- Time Efficient: The sequential washing process completes cleaning in less time compared to conventional manual methods.
- Consistent Cleaning Quality: Controlled spraying, brushing, rinsing, and drying provide uniform cleaning results for every cycle.
- Cost Effective: Reduced water usage and lower labor dependency help decrease long-term operational costs.
- Scalable Design: The prototype can be upgraded in future with sensors, AI monitoring, solar power, and smart automation features.

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IX. FUTURE SCOPES

- Sensor-Based Automation: Integration of IR, ultrasonic, or proximity sensors for automatic vehicle detection and stage activation.
- AI-Based Dirt Detection: Use of image processing or AI systems to identify dirt level and adjust washing intensity accordingly.
- Solar Power Integration: Implementation of solar panels to reduce electricity consumption and improve sustainability.
- Advanced Water Purification: Use of multi-layer smart filtration and UV treatment for higher quality recycled water.
- Automatic Billing System: Integration of digital payment and billing features for commercial car wash stations.
- Multi-Vehicle Support: Expansion of the system for handling different vehicle sizes such as bikes, cars, and SUVs.

X. CONCLUSION

The Eco-Friendly Automatic Car Washing Robot provides an effective solution to the problems of high water consumption, manual effort, and environmental impact associated with conventional car washing methods. The system integrates automated cleaning stages with a water recycling mechanism, enabling efficient and consistent vehicle washing while significantly reducing water usage. The use of biodegradable cleaning agents further enhances its eco-friendly operation. The proposed system can be implemented in urban areas, service stations, and residential complexes to support sustainable infrastructure and water conservation practices.

The results indicate improved efficiency, reduced labor dependency, and reliable performance compared to traditional methods. Although the system requires regular maintenance and proper alignment for optimal functioning, it remains a cost-effective and practical solution for small-scale and domestic applications. Future improvements can include the integration of advanced features to enhance automation and overall system performance.

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