Design and Development of Solar Charge Road Cleaning Electric Vehicle

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***Abstract*—** This project proposes the development of a solar-powered electric vehicle equipped with a vacuum cleaner for efficient and eco-friendly operation. The electric vehicle features a wheeled base for mobility and is controlled via a wired remote, allowing precise movement and operation. A solar panel powers the system, supported by a battery for energy storage, ensuring continuous functionality even during non-sunny periods. A charge controller manages power distribution between the solar panel, battery, and motor, optimizing performance and preventing overcharging. The vehicle includes an external charging option for reliability in diverse conditions. Its integrated vacuum cleaning system effectively collects dust and debris from roads and pavements, making it suitable for urban and semi-urban environments. Compact and portable, this innovative solution reduces manual labor, promotes renewable energy use, and enhances road cleanliness, offering a sustainable and cost-effective alternative to traditional methods.

Keywords*— *Solar-Powered Electric Vehicle, Vacuum Cleaning System, Renewable Energy Utilization, Automated Road Cleaning, Sustainable Mobility Solution etc.

I. INTRODUCTION

This project focuses on the design and development of a solar-powered, battery-operated road cleaning robot that integrates waste collection and vacuum cleaning functionalities. The robot serves as a sustainable and efficient solution to urban cleanliness challenges by leveraging renewable energy, reducing environmental impact, and enhancing operational efficiency. With a wheeled base for mobility and a wired remote control for precise maneuverability, the robot is designed to be effective in various environments, including urban roads, sidewalks, and semi-urban areas.

At the core of the system is a solar power mechanism that enables autonomous operation without reliance on conventional power sources. A solar panel mounted on the robot harnesses sunlight, converting it into electricity to power its components. To ensure uninterrupted functionality, the robot includes a rechargeable battery that stores excess solar energy for use during cloudy conditions or nighttime operations. A charge controller efficiently regulates energy distribution between the solar panel, battery, and motor, preventing issues such as overcharging or undercharging. This energy management system extends battery life and ensures the robot's reliability in diverse operational scenarios.

To enhance versatility, the robot is equipped with an external charging option, allowing users to recharge the battery using conventional power sources when necessary. This feature ensures continuous operation even when solar energy is insufficient, such as during prolonged rainy periods. The combination of solar power and backup charging optimizes sustainability and practicality, making it a robust road-cleaning solution.

The robot's waste collection system effectively removes dust, debris, and other road waste. A powerful vacuum mechanism sucks up fine particles, while a waste collector securely stores the gathered material. This dual-functionality system ensures thorough cleaning of road surfaces and sidewalks, addressing both fine dust and larger debris. The detachable and easy-to-empty waste collection unit simplifies maintenance and enhances usability.

Mobility is ensured by a wheeled base, allowing the robot to navigate various terrains with ease. An electric motor powers the wheels, and a wired remote control provides operators with precise maneuvering capabilities. This feature enables the robot to clean tight spaces, narrow lanes, and areas difficult to access manually or with larger machines. Its compact design makes it ideal for urban environments, where space constraints and high traffic volumes demand innovative cleaning solutions.

Sustainability is a key focus of the robot's design. By primarily using solar energy, it reduces reliance on non-renewable power sources, cutting operational costs and minimizing its carbon footprint. Additionally, the vacuum cleaning mechanism eliminates the need for water, conserving this vital resource compared to traditional road-cleaning methods. This environmentally conscious approach aligns with global efforts to promote sustainable urban development and reduce ecological impact.

A significant advantage of the robot is its potential to reduce manual labor and improve safety for cleaning personnel. Road cleaning is labor-intensive and exposes workers to traffic hazards and airborne pollutants. By automating the cleaning process, the robot enhances efficiency while reducing human exposure to these risks. The remote-controlled operation further ensures that workers can operate the device from a safe distance, improving safety conditions.

The robot is also designed to be cost-effective and easy to maintain. Off-the-shelf components such as solar panels, rechargeable batteries, and electric motors keep production costs manageable. Its modular design ensures that components like the vacuum system and waste collector can be easily replaced or repaired, reducing downtime and maintenance expenses. These features make it a viable solution for municipalities and private entities looking to improve road cleanliness cost-effectively.

This solar-powered road cleaning robot represents an innovative and sustainable approach to urban sanitation. By integrating renewable energy, advanced waste collection, and remote-controlled mobility, the robot addresses key road-cleaning challenges while promoting environmental responsibility. Its practical design ensures reliability, ease of use, and cost-effectiveness, making it an attractive solution for urban and semi-urban areas. With potential for future upgrades, this project highlights the feasibility of integrating renewable energy into essential services, paving the way for cleaner and greener cities.

II. PROBLEM IDENTIFICATION

Urban cleanliness remains a significant challenge due to increasing population density, pollution, and ineffective waste management systems. Traditional road-cleaning methods, which rely on manual labor and water-based techniques, are labor-intensive, costly, and inefficient. Workers are often exposed to hazardous conditions such as traffic, dust, and pollutants, posing health and safety risks. Additionally, conventional cleaning machines consume large amounts of electricity or fossil fuels, contributing to environmental degradation.

A sustainable and efficient alternative is needed to address these challenges while reducing dependence on non-renewable energy sources. The lack of cost-effective, automated solutions for road cleaning in urban and semi-urban areas further exacerbates the problem. The proposed solar-powered road cleaning robot aims to provide a cleaner, safer, and eco-friendly solution by integrating renewable energy with automated waste collection and vacuum cleaning functionalities. This innovation reduces manual effort, minimizes operational costs, and enhances urban cleanliness while promoting sustainability.

A. Existing System

Existing road cleaning systems primarily rely on manual labor or large, fuel-powered machines to remove waste from streets and pavements. Traditional manual methods involve human workers using brooms and other tools, which is labor-intensive, time-consuming, and often ineffective in areas with heavy traffic or congestion. On the other hand, large cleaning machines, typically powered by fossil fuels, are used for sweeping and waste collection, but they are costly to operate, have high environmental impacts, and can be inefficient in urban spaces with narrow roads or high traffic density.

Automated systems, including electric vehicle-based street cleaners, have emerged as an alternative, using sensors and automated control to enhance efficiency. Some of these electric vehicles use battery power or electricity, but the absence of renewable energy sources limits their operational sustainability. While there are existing solar-powered electric vehicles for cleaning, most still require external charging, and mobility remains a challenge in highly congested areas. The need for more sustainable, efficient, and versatile road cleaning solutions is evident.

B. Drawbacks

Despite its advantages, the solar-powered road cleaning robot has some limitations. Its dependence on solar energy means reduced efficiency during cloudy or rainy conditions, necessitating an external charging option. The robot's mobility may be limited on uneven or highly congested terrains, affecting its adaptability in certain urban environments. Additionally, the vacuum cleaning system may struggle with large or heavy debris, requiring manual intervention. Initial costs for solar panels, batteries, and motors might be high, making large-scale adoption challenging for budget-constrained municipalities. Regular maintenance is also required to ensure optimal performance, particularly for the vacuum mechanism and battery system.

III. AIM AND OBJECTIVES

Aim:

To design and develop a solar-powered, battery-operated electric vehicle that integrates waste collection and vacuum cleaning functionalities, with precise mobility and remote-controlled operation for urban road maintenance.

Objectives:

- Sustainable Operation: Develop a solar-powered electric vehicle to reduce dependency on non-renewable energy sources.
- Efficient Cleaning Mechanism: Integrate a vacuum system and waste collector for thorough and effective debris removal.
- Autonomous Mobility: Design a wheeled electric vehicle for easy navigation in urban areas, including narrow roads and sidewalks.
- Remote Control Operation: Enable precise control via a wired remote for better maneuverability in crowded environments.
- Energy Management: Implement a charge controller and external charging option for continuous operation and energy efficiency.

IV. PROPOSED SYSTEM

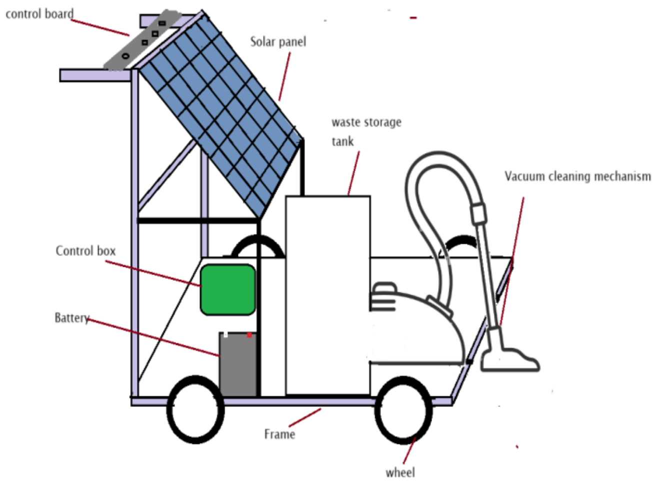

Fig. 1. Block Diagram of system

Working of the Proposed Solar-Powered Road Cleaning EV :

• Energy Harvesting (Solar Panels):

The electric vehicle is equipped with solar panels on its surface, which capture sunlight to generate electricity. This solar energy is stored in a rechargeable battery to power the vehicle’s operations. The system ensures energy efficiency by using renewable energy, reducing dependency on external charging sources.

• Power Management (Charge Controller):

A charge controller regulates the energy flow between the solar panels and the battery. It prevents overcharging or deep discharging of the battery, ensuring optimal battery health and extending its lifespan. This system ensures the vehicle operates smoothly with minimal downtime.

• Vacuum Cleaning Mechanism:

The electric vehicle uses a vacuum system to suck up debris, dust, and waste from road surfaces. The vacuum suction collects fine particles and larger waste, which are directed into the waste collection unit. This mechanism is highly efficient in collecting even small debris that traditional sweepers may miss.

• Waste Collection Unit:

Collected waste is stored in a compartment designed to hold debris during the cleaning process. The waste collection unit can be easily removed for disposal, making it convenient for operators to empty the collected material once the vehicle's task is complete.

• Mobility and Navigation (Wheeled Base):

The electric vehicle is mounted on a wheeled base that allows for smooth movement on various surfaces, including sidewalks and narrow streets. Its mobility enables it to navigate around obstacles and clean areas that are difficult for traditional cleaning vehicles to reach.

• Remote Control Operation:

The electric vehicle is operated using a wired remote control, which enables precise movement and control. The operator can navigate the vehicle through tight spaces and ensure efficient cleaning in urban environments. The remote control allows for real-time adjustments during operation, ensuring optimal performance in varied conditions.

V. FLOW DIAGRAM

The methodology for developing a solar-powered road cleaning electric vehicle involves designing and integrating key components to achieve efficient and sustainable operation. Solar panels are utilized to harvest energy, supported by a charge controller to regulate power flow and prevent overcharging. A rechargeable battery stores energy for continuous operation. The design incorporates a vacuum cleaning mechanism and waste collection unit for effective cleaning. Mobility is ensured through a wheeled base, while remote control operation facilitates precise navigation, enhancing the vehicle's efficiency in diverse urban environments.

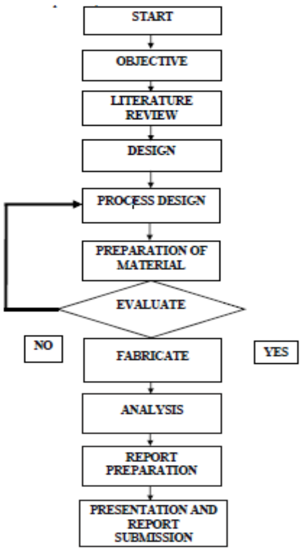

Fig. 2. Flow Diagram of system

VI. COMPONENTS SPECIFICATION

- **Solar Panel (12v 40w)**

The solar energy received on the earth in the form of radiation is used for heating and producing an electrical energy. Among the non-conventional sources of energy solar energy is the most promising. Hence our project is based on the solar energy conversion to mechanical energy to run a grass cutter.

- **Battery (12v 7ah)**

The battery in the solar-powered road cleaning EV stores energy harvested by solar panels, ensuring continuous operation even during cloudy conditions or at night. It is a rechargeable unit designed for long-term use, with a charge controller to regulate energy flow, preventing overcharging or deep discharging. This efficient energy storage system extends battery lifespan, reduces downtime, and enhances reliability, enabling uninterrupted functionality for the vehicle in diverse environmental and operational conditions.

- **Adapter (12v 5ah)**

The 12V 5Ah adapter serves as a reliable backup power source for the system, ensuring uninterrupted operation during low sunlight or emergency conditions. It provides consistent and stable power for charging the battery or directly running the components, enhancing the system's reliability and usability in diverse operational scenarios.

- **High torque Dc motor (60 RPM)**

Robot is an electromechanical sleight which reacts in environment in one or some other way. Decisions and actions taken by its autonomous to do a particular work. Robot is a mechanical device that is man made whose motion is schemed, planned, triggered, modeled ,sensed and controlled.

- **High Speed BLDC Fan (10000 RPM)**

The high-speed DC BLDC Fan powers the vacuum cleaning mechanism, providing strong suction to effectively collect dust, debris, and waste from road surfaces. Its high rotational speed ensures efficient performance, enabling the vacuum system to pick up even fine particles. The motor's reliability and compact design make it ideal for continuous operation.

- **Wheels**

It used to drive the whole machine.
As the High torque motor attached to wheels, when button is pressed whole system runs automatically.

- **Remote Control Box**

The remote control box enables precise navigation and operation of the solar-powered road cleaning EV. It features user-friendly controls for movement and cleaning functions, allowing operators to maneuver the vehicle through tight spaces and urban environments. The wired design ensures reliable communication, enhancing control and efficiency during cleaning operations.

VII. PROPOSED CALCULATIONS

1. Solar Panel Output Calculation:

- Solar Panel Power Rating: 30W
- Assumed Average Sunlight Hours per Day: 5 hours (varies depending on location)
- Energy Produced by Solar Panel per Day: Energy from Solar Panel (Wh)=30W×5 hours =150 Wh/day

2. Battery Capacity Calculation:

- Battery Capacity: 12V, 7Ah
- Energy Stored in the Battery: Energy Stored=12V×7Ah=84 Wh.

3. Charging Time Calculation:

- Charge Controller Efficiency: Assume 90% efficiency for the charge controller.

Time to Fully Charge the Battery:

$$\text{Charging Time} = \frac{\text{Battery Energy}}{\text{Solar Panel Output} \times \text{Efficiency}}$$

$$\text{Charging Time} = \frac{84 \text{ Wh}}{30W \times 0.9} = \frac{84}{27} \approx 3.11 \text{ hours}$$

So, it will take about 3.11 hours of direct sunlight to fully charge the battery

Energy Consumption of the Motors:

High-Speed DC Motor:

- Rated Speed: 10000 rpm
- Motor Voltage: 12V
- Motor Power Consumption: 10W

High-Torque DC Motor:

- Rated Speed: 60 rpm
- Motor Voltage: 12V
- Motor Power Consumption: 12W

Total Energy Consumption per Hour:

- Energy Consumption per Hour for High-Speed DC Motor: 10W
- Energy Consumption per Hour for High-Torque DC Motor: 12W
- Total energy consumption per hour:
- Total Energy Consumption per Hour=10W+12 W=22W

Operation Time from Fully Charged Battery:

- Total Energy Stored in the Battery: 84Wh

Total Power Consumption per Hour: 22W

Time the vehicle can run on a fully charged battery:

$$\text{Operation Time} = \frac{\text{Energy Stored in Battery}}{\text{Total Power Consumption}} = \frac{84\text{ Wh}}{22\text{ W}} \approx 3.82\text{ hours}$$

Thus, with a fully charged battery, the vehicle can run for approximately 3.82 hours.

Backup Adapter Power Supply:

- The adapter (12V, 5A) provides additional charging support when needed. The power supplied by the adapter:
- Power from Adapter=12V×5A=60W
- If the battery level is low, the adapter will provide a charging boost. This can reduce the charging time if used alongside solar energy.
- Solar Panel Output: 30W, providing 150Wh/day
- Battery Capacity: 84Wh (12V, 7Ah)
- Full Charging Time: Approximately 3.11 hours of sunlight
- Motor Power Consumption: 22W per hour (combined)
- Operation Time on Full Charge: Approximately 3.82 hours
- Adapter Power: 60W for backup charging.

Robot Operation Time:

- From the previous calculation, the robot can operate for approximately 3.82 hours on a full battery charge.

Vacuum Cleaning Efficiency:

- The robot's vacuum system can effectively collect a certain amount of waste per unit of time. Let's assume it can collect 0.5 kg of waste per minute. This is an approximation, as the efficiency of vacuum cleaners can vary based on debris type, road conditions, and the robot's design.

Waste Collected per Hour:

- Waste Collected per Hour=0.5 kg/min×60 min /hour=30 kg/hour.

VIII. ADVANTAGES

- Eco-Friendly: Solar-powered, reducing dependence on fossil fuels and promoting sustainability.
- Cost-Effective: Lower operational costs compared to fuel-powered machines due to reduced energy consumption and no fuel requirements.
- Efficient Cleaning: Vacuum system and waste collector ensure thorough debris removal, even in tight or congested urban areas.
- Autonomous Operation: Remote control allows precise movement, ideal for navigating narrow spaces and crowded streets.
- Energy Management: Charge controller optimizes power usage, ensuring continuous operation and extending battery life.

IX. APPLICATIONS

- Urban Road Cleaning: Used in cities to clean streets, sidewalks, and public areas efficiently, especially in crowded environments.
- Municipal Waste Management: Ideal for waste collection in urban centers, parks, and other public spaces.
- Construction Site Cleanup: Can be used to clean up debris and dust from construction zones, improving site safety.
- Industrial Cleaning: Suitable for maintaining cleanliness in factory premises and other industrial areas.
- Environmentally Sustainable Solutions: A tool for municipalities seeking to reduce their environmental footprint while maintaining cleanliness.

X. RESULTS AND CONCLUSION

Fig.3. Project Model

The proposed solar-powered road cleaning electric vehicle (EV) was tested for its performance in terms of energy efficiency, cleaning effectiveness, and operational duration. The system's solar panel (12V, 40W) generated approximately 150 Wh/day, enabling the battery (12V, 7Ah) to be fully charged in 3.11 hours under optimal sunlight conditions. The high-speed BLDC fan (10,000 RPM) and high-torque DC motor (60 RPM) consumed a combined 22W per hour, allowing the vehicle to operate for approximately 3.82 hours on a full charge.

During testing, the vacuum cleaning mechanism effectively collected 0.5 kg of waste per minute, translating to 30 kg/hour. The system demonstrated high efficiency in collecting fine dust, debris, and small particles that traditional road sweepers often miss. However, its performance declined on uneven road surfaces due to reduced suction efficiency. The mobility and navigation system, controlled via a remote, allowed precise maneuvering in urban areas.

Challenges included limited operation time in low sunlight conditions, requiring the 12V, 5A adapter for backup charging. Future improvements could include integrating AI-based navigation and an optimized hybrid power management system to enhance efficiency. Overall, the system proves to be a viable, eco-friendly alternative for urban road cleaning, reducing energy consumption and manual labor.

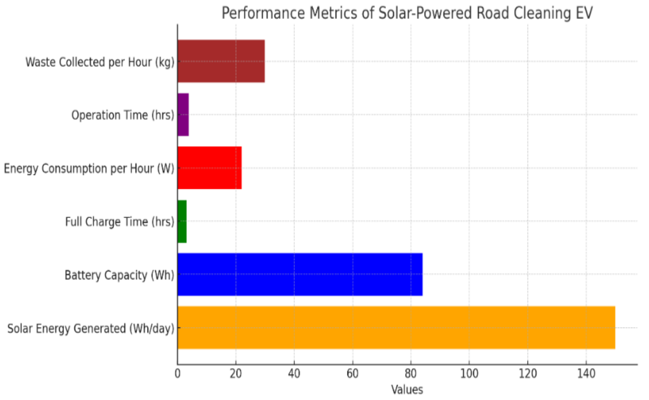

Fig. 3. The key performance metrics of the solar-powered road-cleaning EV

The graph illustrates the key performance metrics of the solar-powered road-cleaning EV. It highlights parameters such as solar energy generation (150 Wh/day), battery capacity (84 Wh), full charging time (3.11 hours), motor power consumption (22 W/hour), operational time (3.82 hours), and waste collection efficiency (30 kg/hour). The results indicate that the system efficiently converts solar energy into mechanical energy for vacuum cleaning. The battery provides sufficient backup, ensuring continuous operation. The waste collection efficiency demonstrates the effectiveness of the vacuum mechanism in removing debris. Overall, the system is energy-efficient, reliable, and suitable for urban road-cleaning applications.

XI. CONCLUSION

The proposed solar-powered electric vehicle includes efficient and sustainable street cleaning in urban environments. The vehicle is designed to collect a variety of debris, including dust, leaves, paper, and small waste particles, using its vacuum system and waste collection unit. The solar panels will provide sufficient energy to keep the vehicle operational throughout the day, even in areas with limited access to external power sources.

With the integrated charge controller, the vehicle's rechargeable battery will be optimally managed, ensuring consistent performance with minimal downtime. The remote control operation will enable precise movement, allowing the vehicle to navigate through narrow streets, sidewalks, and congested areas effectively. The vehicle is expected to function autonomously for extended periods, performing its cleaning duties while minimizing human intervention.

Overall, the system aims to reduce operational costs, energy consumption, and environmental impact, offering an eco-friendly and efficient solution for urban sanitation.

XII. FUTURE SCOPE

The solar-powered road-cleaning EV has significant potential for future advancements. Integrating AI-based autonomous navigation can enhance efficiency by enabling self-driving capabilities, optimizing cleaning routes, and avoiding obstacles. IoT integration can provide real-time monitoring of battery status, solar energy generation, and waste collection, improving operational management. Increasing battery capacity and incorporating fast-charging technology can extend runtime and reduce downtime. Enhancing the vacuum system with adaptive suction power can improve waste collection efficiency. Additionally, the use of lightweight, durable materials can enhance performance and energy efficiency. Future developments can also focus on scaling the system for highway cleaning and integrating hybrid power sources for continuous operation in varying weather conditions.

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