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Design and Implementation of Automatic Solar Panel Cleaning Robot

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Abstract: Photovoltaic panels, organized in arrays within solar farms or systems, serve as the primary source of solar power generation. While solar energy is favored in sun-rich regions for its cleanliness, the efficiency of PV panels is susceptible to decreased performance due to the accumulation of dust and debris, even on a single panel within an array. This has sparked a global interest in sustainable energy production and being more energy-efficient. Many industrial applications now rely on solar panels as their primary source of electrical power, In order for the photovoltaic cells to operate at optimum efficiency without any loss of energy, the panel surface should be free of dust and any other kind of particle which obstructs the flow of photons. Consequently, regular cleaning of PV panels is essential. Analysis of dust composition revealed a variety of pollutants, such as ash, sand, silica, calcium carbonate, and crimson soil. By employing a computerized cleaning scheme, the research demonstrated the potential to expand power output by approximately 30%. Current manual cleaning methods consume significant time, water, and energy resources and also there is a lack of automation. To overcome this problem, a fully automatic solar panel cleaning robot is proposed. The robot's movements during the cleaning process are controlled by an Arduino controller system. It is equipped with a microfiber brush and a water pump system to effectively remove dust and debris from the PV panel surfaces.

Keywords: solar panels, stepper motors, Arduino microcontroller, sustainability, energy efficiency, automatic solar panel cleaning system, Photovoltaic panels

1. Introduction

In today's world, energy-related issues are getting more critical. This has sparked a global interest in sustainable energy production and being more energy-efficient. Many industrial applications now rely on solar panels as their primary source of electrical power, In order for the photovoltaic cells to operate at optimum efficiency without any loss of energy, the panel surface should be free of dust and any other kind of particle which obstructs the flow of photons. Dust can reduce a PV panel's efficiency by as much as 25% to 30%, depending on the environmental conditions. To address these challenges, the development of a systematic and efficient robotic device for large-scale panel cleaning with minimal water usage is essential. Water is utilized in the cleaning process, as it is known that many commercial crystalline silicon photovoltaic cells exhibit favorable current-voltage characteristics at lower temperatures. This relates to the use of water sprayed onto photovoltaic cells, which can improve efficiency by more than 15%. One notable advantage of adopting automated robotic solutions for solar panel cleaning is the inherent robustness, thoroughness, reproducibility, and optimized cleaning speed when compared to traditional cleaning methods.

Increase in age results in unintentional falls which is a matter of concern [2]. Falls causes both physical and mental injury in elderly people that they need to be depends on someone else. Once fall happen it is necessary to provide immediate medical assistant in a golden hour before injury become severe so this system

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will provide immediate alert to the caregiver and family members so that medical care should be provided as soon as possible [3].

Falls results in social as well as economic impacts and it has been estimated that it will be 15% of total population worldwide at the end of 2050 and the percentage of fall accident is more in the people who leave at home with 40 percentages more than one. Most of the falls occur during the activities of daily leaving which involves small loss of balance while walking and standing [4]. Falls can result in severe injuries that are leading to the inactivity of whole body which may result in increased isolation and health deterioration. These incidences may cause significant economic expenses hence we build a mobile system which uses smart shoe sensors to predict falls and smartphone to alert the user of a fall before it happens. Automatic fall detections currently are classified into 3 types on the basis of sensors; they are video- based, wearable sensor based and acoustic based methods. Also, many sensors depend upon significant installations and trainings which lack to give appropriate outcome and hence contribute to a poor system. Nowadays, we can use smartphone-based fall detection systems as they are portable anywhere. This system detects cautious gait patterns and whenever needed warns the user by giving audio messages or vibrations and calls the caretaker if the user falls with the exact location of him. Video based methods uses high frequencies to detect cautious gait, also expert calculations are not cost recommended whereas wearable sensors-based methods require extra sensors for motion sensing on foot, waist and wrist which includes gyroscopes, strain gauges, accelerometers etc. They measure various attributes of human walking patterns [5]. These produce various outcomes which are used for classification of gait pattern. In this paper we are considering smart phone-based fall risk detection with shoe-worn sensors. As smart phones are very much portable and have the ability to work anywhere. With the help of growing mobile technology, the smart phone-based fall risk detection can be used anywhere. These systems have become more popular because of the development of computational abilities. Hypothetically, the forces sensor-shoes can also analyse cautious patterns. Hence to develop it practically, we are focusing to make smart shoe for fall risk prediction, detection and for analysing gait. Knowing the standards for normal walking is necessary to comprehend or identify abnormal gait patterns. Normal walking is produced by balanced muscle contraction, joint movement, and sensory perception. People who are healthy can stand up straight and alter their position to find the balance and stability they want while walking on two legs [7]. The arm swing has an impact on the pelvis, causing it to rotate and inclination periodically. Additionally, the angles at the ankle, knee, and hip shift as you move to improve coordination. As a result, the regular gait is periodic and characterized by balance and coordination [8]. A set of parameter results from a quantitative investigation of gait stability and gait symmetry have been obtained when walking speed decreases with age and has an impact on comfortable walking pace. Based on this, we created an early warning system that predict risk of fall while walking [9]. Pressure sensors utilizes the pressure exerted on the foot while strolling. To survey the stress dissemination, here we have used four pressure sensors which are put on shoe innersole. From that four force sensors, two are inserted in the front side of the toe and the other two are in the back side of the toe. The communication module is composed of two components which are Arduino UNO and Wi-fi module with electric supply. The Arduino is an open-source platform with a simple input and output system. In this module the signal is first amplified and then transfers the amplified signal to the smart phone through the Wi-Fi communication module [14]. For processing the data, there are two different software tasks in the communication module, from which one is for Arduino and another is for android. We have programmed an Arduino to read signals from the pressure sensors whose values are in the form of analog signals and to form an envelope of the data that converts analog signals into digital form [15]. Eventually Arduino sends those envelopes of data to the smartphone. Smartphone collects pressure data to record different walking patterns for the same subject over a span of time to identify the abnormality in a strolling pattern. Hence to identify if the gait is cautious or not, we have used the Decision Tree Method. In this paper, we have used the Decision Tree algorithm to classify the data. It is a popular machine learning algorithm as it takes less effort for data preparation, hence its time complexity is less as compared to all algorithms, also it gives a good accuracy of 91%. In this algorithm, it comprises branches and nodes. The nodes are connected by branches. The top nodes of the decision tree are known as root-nodes, which consist of all the training data. All these root-nodes are called decision nodes. These decision nodes are further split into two classes also called as sub-tree by comparing the normal and abnormal values. This paper seeks to address the issue of senior citizens' falling, which causes a serious threat to their health. As a result, it was crucial to suggest a smart system that anticipates falls before they happen, using devices that are installed on the elderly to alert caretakers of this so that he takes immediate action to avoid injuries. Hence a machine learning technique-based system to anticipate falls in elderly and disabled has been presented. To build this system, we use a decision tree making algorithm because it gives faster response as compared to other algorithms and gives accuracy of 91%. We plan to prioritise data design for better performance in the future in order to enhance the prototype. We have used SIM 900A GSM module in our paper for sending SMS to the caretaker and for calling purpose. This module is made up of Dual Band GSM/GPRS based on SIM900A modem from SIMCOM. It works on frequencies 900/ 1800 MHz. The GSM/GPRS Modem has internal TCP/IP stack to enable us to connect with internet via GPRS. This GSM module is with a very powerful single-chip processor integrating AMR926EJ-S core, allowing you to benefit from small dimensions and cost-effective solutions. As discussed earlier this paper is mainly focusing on the sole pressure which helps in predicting the fall in future. So, we need several pressure values at different points like Front- Foot (FF), Mid-foot (MF) and Rear-foot (RF) for predicting the fall.When a person walks normally, pressure is distributed evenly on the foot, this is considered as normal gait pattern but when a person is about to, uneven pressures are exerted on the fore-foot and rear-foot. This is considered as abnormal gait pattern. Gait abnormality causes huge health problems in the people all over the world this injury can result in physical inactivity, poor quality of life and sometimes death [1]. Many research projects have already been taken place on the human gait analysis which says that by the end of 2050 one in five in worldwide will be age 65 or over can definitely face this problem. Falls are common in elderly approximately 30-50% of elderly population faces it every year. In the age group of 70 to 75 year's its 30% per year. to develop a smart shoe that detects falls in the elderly and disabled using a machine learning algorithm. This paper suggests a machine learning-based fall prevention and detection system that can improve someone's quality of life by protecting them from accidents without needing their help. Our analysis indicates that the decision tree technique is the best machine learning algorithm, and this is how our system prototype detects falls. It is made up of a smartphone, a Wi-Fi connection module, and a smart shoe with four pressure sensors. People who are physically impaired or elderly are more likely to fall, which can result in fatalities or serious injuries. The main objective of this research is to create and apply a novel approach.

These incidences may cause significant economic expenses hence we build a mobile system which uses smart shoe sensors to predict falls and smartphone to alert the user of a fall before it happens. Automatic fall detections currently are classified into 3 types on the basis of sensors; they are video- based, wearable sensor based and acoustic based methods. Also, many sensors depend upon significant installations and trainings which lack to give appropriate outcome and hence contribute to a poor system. Nowadays, we can use smartphone-based fall detection systems as they are portable anywhere. This system detects cautious gait patterns and whenever needed warns the user by giving audio messages or vibrations and calls the caretaker if the user falls with the exact location of him.Video based methods uses high frequencies to detect cautious gait, also expert calculations are not cost recommended whereas wearable sensors-based methods require extra sensors for motion sensing on foot, waist and wrist which includes gyroscopes, strain gauges, accelerometers etc. They measure various attributes of human walking patterns [5]. These produce various outcomes which are used for classification of gait pattern. In this paper we are considering smart phone-based fall risk detection with shoe-worn sensors. As smart phones are very much portable and have the ability to work anywhere. With the help of growing mobile technology, the smart phone-based fall risk detection can be used anywhere. These systems have become more popular because of the development of computational abilities. Hypothetically, the forces sensor-shoes can also analyse cautious patterns. Hence to develop it practically, we are focusing to make smart shoe for fall risk prediction, detection and for analyzing gait.

This study catalysis further exploration into the integration.

2. Literature Review

Researchers have explored numerous approaches for the automatic self-cleaning of solar panels. Research in 2015 proposed an automated cleaning mechanism featuring dirt-detecting sensors and sliding brushes controlled by an 8051 series microcontroller.

Analysis of dust composition revealed a variety of pollutants, such as ash, sand, silica, calcium carbonate, and crimson soil. By employing a computerized cleaning scheme, the research demonstrated the potential to expand power output by approximately 30%.

A study conducted in Libya highlighted the issue of dust and sand accumulation on PV panels due to the region's climate, leading to reduced sunlight reaching the modules. This research sought a solution by implementing weekly water washing of PV panels during specific periods and measuring the performance before and after cleaning. The study found that such periodic washing improved the performance of PV panels.

Efforts have also been made to design electro-dynamic self-cleaning PV modules. These designs indicated that the rate of dust elimination increased with higher voltage. However, such cleaning methods have limitations, including the inability to remove muddy or adhesive particles, as they lack liquid-based cleaning components and can be expensive in terms of both initial setup and operation costs.

Moreover, several researchers have focused on studying the impact of dust settlement, wind speed, and humidity on PV modules, emphasizing the interdependencies among these factors. They highlighted the necessity of simultaneous measurements to comprehensively understand their influence.

3. DIFFERENT CLEANING METHODS

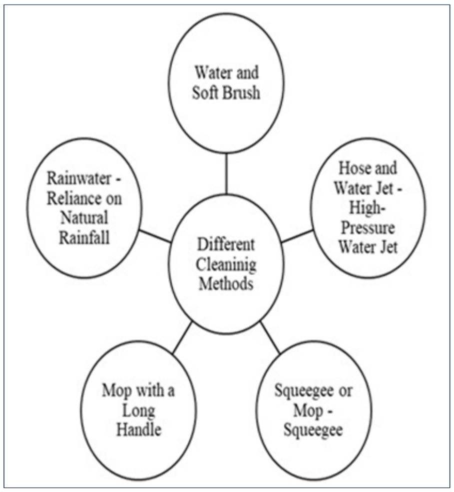

Fig 1: Methods implemented for cleaning solar panels

A. Water and Soft Brush:

To clean solar panels using a water and soft brush method, begin by filling a bucket with clean water. Submerge a soft brush or sponge into the water, creating a mild cleaning solution. Gently scrub the solar panels, starting from the top and working downward. It's crucial to avoid abrasive brushes that may scratch the panels. Regularly rinse the brush to prevent debris buildup, ensuring an effective and scratch-free cleaning process. This simple yet effective technique helps maintain the efficiency and longevity of solar panels without the need for specialized equipment.

B. Hose and Water Jet - High-Pressure Water Jet:

Using a hose with a high-pressure nozzle is an efficient method for cleaning solar panels. Direct the water jet onto areas with visible dirt, allowing the force to dislodge contaminants. Adjust the pressure to avoid damage, and consider using a squeegee afterward for a streak-free finish. This approach ensures effective cleaning without the need for manual scrubbing, contributing to the overall efficiency and performance of solar panel systems. Regular adjustments and care are necessary to prevent potential harm to the panel.

C. Mop with a Long Handle:

For cleaning solar panels, attaching a soft mop to a long handle proves effective. Wet the mop and clean the panels, ensuring comprehensive coverage. Opting for a non-abrasive mop surface to prevent potential damage. This method, especially suitable for large installations, facilitates reaching elevated surfaces efficiently, contributing to the regular maintenance and optimal performance of solar panel arrays.

D. Squeegee or Mop – Squeegee:

To clean solar panels with a squeegee, begin by wetting the panels with water and then systematically use the squeegee to remove water and contaminants, starting from the top and working downward. It's crucial to select a squeegee with a soft rubber blade to prevent any potential scratching of the panel surface. For optimal results, perform the cleaning either in the early morning or late afternoon to avoid direct sunlight, minimizing the risk of streaks and ensuring a clear, debris-free surface that enhances the efficiency of the solar panels.

E. Rainwater - Reliance on Natural Rainfall:

Relying on natural rainfall is a simple method for cleaning solar panels. Allowing rain to naturally wash away light dust and debris can contribute to maintaining panel efficiency. However, this approach may not be adequate in areas with infrequent or insufficient rainfall. Therefore, regular inspections are recommended to ensure optimal cleanliness..

4. COMPONENTS

1) *Arduino UNO:*

Fig2: Arduino UNO

The Arduino Uno is a widely-used microcontroller board featuring an ATmega328P chip, offering 14 digital I/O pins, 6 PWM outputs, 6 analog inputs, and USB connectivity for easy programming. It operates at 5V and 16 MHz.

2) *Li-ion battery:*

Fig 3: Li-ion Battery

Li-ion, short for lithium-ion, is a type of rechargeable battery known for its efficiency and ability to store a significant amount of energy. In this project, 3000mAh battery is used, which means that the battery can provide a current of 3000 milliampere-hours. This high capacity means that the battery can keep the robot running for an extended period before needing a recharge.

3) *Solar panel:.*

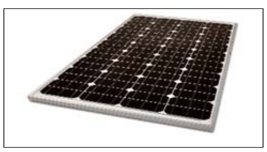

Fig 4: Solar Panel

Solar panels are a remarkable technology that transforms sunlight into electricity, offering a clean and sustainable energy source. In this project, these are used as an effective means to charge lithium-ion (Li-ion) batteries in an eco-friendly manner. This energy can be stored and later used to power devices, even when the sun isn't available, such as during the night.

4) *Ultra Sonic Sensor:*

Fig 5: Ultrasonic Sensor

In this project, HC-SR04 ultrasonic sensor is employed. This sensor module has four pins, namely Vcc, Trigger, Echo, and Ground. Its operation relies on a simple principle: the sensor sends out an ultrasonic wave, which travels through the air. When this wave encounters an obstacle, it bounces back toward the sensor. The sensor then detects this reflected wave, allowing us to calculate the distance to the object or obstacle in front of it. The formula to calculate distance is,

$$\frac{distance}{1} = \frac{duration * 0.034}{2}$$

5) *HC-05 Bluetooth Module:*

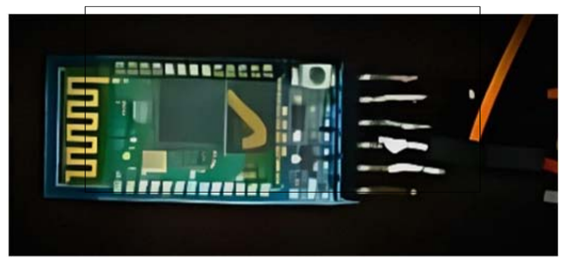

Fig 6: Bluetooth Module

The HC-05 Bluetooth Module is a versatile and widely-used Bluetooth communication device known. The HC-05 can be configured as a master or slave device, making it adaptable for various applications. It also supports serial communication (UART). With a range of up to 10 meters in a typical environment, the HC-05 module is widely employed in applications such as wireless data transmission, remote control, automation, etc.

6) *L293D Motor Driver:*

The L293D Motor Driver serves as a fundamental component for controlling and driving direct current (DC) motors. The L293D enables motors to be driven in both forward and reverse direction. It also has built-in diodes to safeguard against voltage spikes and back-electromotive force ensuring the longevity and reliability of the motors and the IC itself.

7) *DC Motor:*

Fig 7: DC Motor

a) *Wheel Movement:*

To facilitate the movement of the robot, 2 12V DC motor operating at 300 RPM are employed. These motors feature durable steel gears and pinions, ensuring extended lifespan and improved resistance to wear and tear.

b) *Brush Movement:*

For the operation of the cleaning brush, a 12V DC motor with a speed of 500 RPM is used in this project. This motor is designed with robust construction equipped with high-quality gears.

8) *Water Pump:*

A water pump is employed to gently spray water onto the PV panel through a specialized nozzle during the cleaning process. Specifically, a 12V DC water pump with a pressure of 100 PSI is utilized for this purpose

9) *Wheels and Track Belt:*

In this project, four wheels are affixed to both sides of the frame to facilitate smoother movement. To prevent slipping and secure the wheels in place, a rubber track belt is utilized.

5. WORKING

In the design and assembly of the wireless cleaning robot, various components are integrated together to create an efficient and remotely controlled cleaning system for solar panels. The core of the robot's functionality lies in its 12V battery, which powers the motors that drive its movement. A track belt, cleverly positioned over the wheels and linked to the motors, facilitates smooth traversal across the surface of solar panels. Activation of the robot is conveniently done through a mobile device, providing users with remote control capabilities.

Upon remote activation, the motors spring to life, propelling the robot and simultaneously initiating the spraying and cleaning mechanisms. The water required for cleaning is precisely sprayed onto the solar panels through a strategically placed nozzle, driven by a water pump. This targeted spraying ensures efficient cleaning without unnecessary water wastage. As the robot progresses along the surface of the solar panels, it continually cleans and removes accumulated dirt and debris.

The command is provided, the ultrasonic sensor HC-SR04 comes into play. The sensor is supplied with a 5V power. Its 'trig' pin connected to the pin 3 of Arduino is triggered. Its sends an ultrasonic wave which transmits further and reflects back from the ground at the 'echo' pin, connected to pin 2 of Arduino. Depending upon the total time required for the signal to transmit and receive the distance is available to move forward safely, is estimated. A Bluetooth module HC05 is which runs on 5V supply transfers signals to the Arduino for movement in different directions. The directions of movement of the cleaner can be controlled using any serial controller app by interfacing it to the Bluetooth module.

For the actual movement of the wheels, L293N motor driver is used, which works on a 12V power supply. Its enA, enB, in1, in2, in3, in4 pins are connected to the pins 5,6,7,8 of the Arduino which help in the direction & speed control. Thus, the four motors connected to the out1, out2, out3, out4 pins of the motor driver will provide the required movement.

Further, as the panel cleaner moves over the solar panels, a water pump provides the water from the stored water supply. Another L293N motor driver which works on a 12V supply & is connected to the brush at the output, cleans away the dust from the solar panels effectively thus, increasing its efficiency.

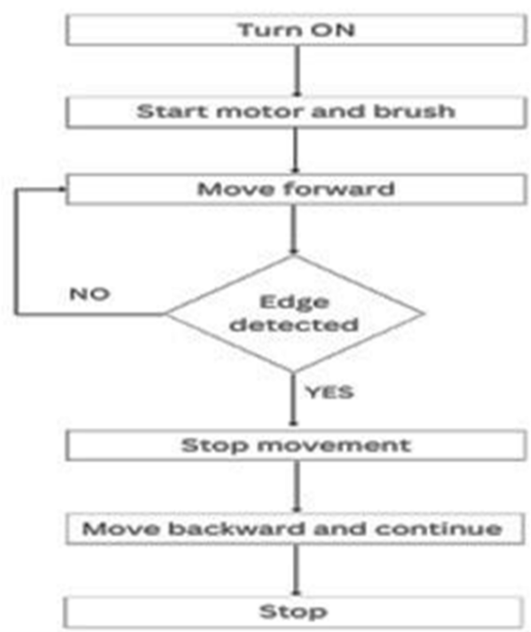

Fig 8: Working of Automatic Solar Panel Cleaning Robot

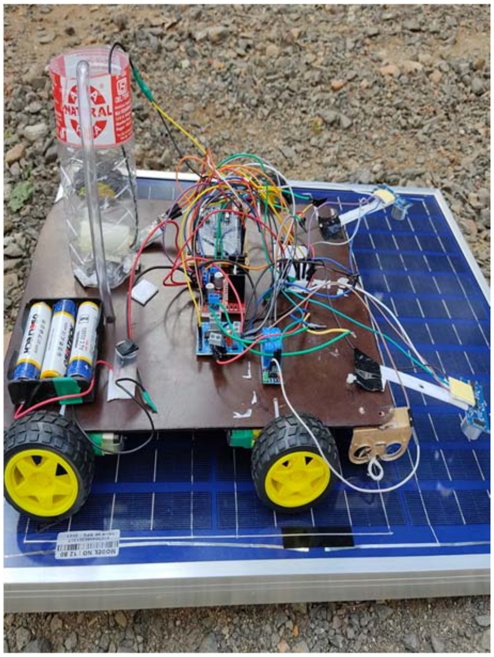

Fig 9: Automatic Solar Panel Cleaning Robot

6. RESULTS

The cleaning robot efficiently removes accumulated dirt and dust from the surface of the solar panel. The robot not only ensures a thorough cleanup but also leads to substantial cost savings, reducing cleaning expenses up to 80% in comparison to manual cleaning methods. Moreover, the cleaning process enhances the efficiency of the solar panel by approximately 25%, allowing it to generate more power. An additional environmental benefit is the significant reduction in water consumption when cleaning the panels. It can be adapted to fit panels of various sizes, making it a practical and universal solution for solar panel maintenance. The following are some of the advantages the cleaning robot brings:

1) *Manpower Savings:*
   The robotic system significantly reduces the time required for solar panel cleaning compared to manual methods, resulting in reduced overall labour hours.

2) *Enhanced Cleaning:*
   Unlike manual cleaning, which struggles with stubborn and sticky dirt, the cleaning robot effectively removes such contaminants.

3) *Water Conservation:*
   Unlike conventional cleaning methods that tend to use excessive water, the proposed system allows for precise control of water usage through nozzles and valves.

4) *Versatility:*
   This portable device is adaptable to various panel sizes, making it suitable for cleaning almost any panel.

5) *Cost-Efficiency:*
   The robotic system can cover a larger area per charge and consume less water, resulting in significant reduction in the cost of cleaning per unit area.

6) *Remote Controlling and monitoring:*
   The cleaning robot can be operated remotely using mobile devices, allowing for convenient and flexible control.

7. CONCLUSION

The accumulation of various forms of dust, whether biological or chemical, on solar panels has a detrimental impact on photovoltaic (PV) performance, resulting in decreased solar PV output power. Effective cleaning and maintenance are, therefore, important aspects of ensuring optimal solar panel efficiency. The project has demonstrated a remarkable increase in efficiency for large solar panel arrays.

Thorough cleaning is highly beneficial because even a single panel clogged with dust can reduce the efficiency of the entire array. It's vital that all individual cells operate at their best performance since they are interconnected in a series. Existing methods of PV panel cleaning include natural methods and manual methods. However, taking into consideration the merits and limitations of these methods, it is evident that an automatic brush-type solar panel cleaning approach holds significant advantages. This approach requires minimal water for dust removal, making it a water-efficient solution. Furthermore, it is cost-effective and can be indigenously developed.

8. FUTURE SCOPE

The project offers substantial potential for improvement, focusing on increasing its attractiveness in the market and enhancing operational efficiency. In the next development phase, efforts can be directed towards streamlining the system, making it more adaptable for large-scale production by reducing its size and weight while maintaining its eco-friendly principles. Key areas of improvement include enhancing the robot's adaptability, speed, durability, and decision-making capabilities.

Thermal camera modules and proximity sensors can be integrated to improve panel inspection and interaction. The incorporation of Internet of Things (IoT) technology would play a crucial role, facilitating real-time monitoring and control and allowing users to easily track the robot's performance via a smartphone app or web interface.

The integration of machine learning algorithms would also enable the robot to adapt to changing environmental conditions and optimize its cleaning routines. To enhance reliability and reduce downtime, predictive maintenance

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