

Smart Dust Detection and Automated Cleaning for Photovoltaic Systems in Hydroponic Farming Applications

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Abstract

The efficient operation of photovoltaic (PV) systems is significantly impacted by dust accumulation on solar panels, which can reduce power output. To combat this, a smart dust detection and automated cleaning system has been developed, utilizing low-cost dust sensors placed across the PV array to monitor dust levels continuously. The data is transmitted to a central control unit that employs advanced algorithms to determine optimal cleaning schedules based on predefined cleanliness thresholds. When significant dust accumulation is detected, the system activates an automated cleaning mechanism involving an ESP32 microcontroller, DC motors, a water pump, and a motor driver. This approach has demonstrated a notable improvement in voltage output and reduced energy losses while minimizing manual maintenance efforts. Overall, the system enhances the efficiency and performance of PV installations, contributing to their sustainability and longevity by optimizing energy generation and reducing downtime and maintenance costs.

1. Introduction

Many studies have confirmed that the reduction of solar photovoltaic energy production performance occurs when there is dirt and dust on the surface of the solar photovoltaic. Next, the cleaning system for solar photovoltaics is still run manually, which requires a specialist to operate the solar photovoltaic cleaning machine. In addition, consumers have difficulty monitoring the data produced and the condition of the solar photovoltaic because of its location, which is usually on the roof. So, the dirt and dust must be cleaned because it has a significant impact on the performance of solar photovoltaics are determined by a variety of factors and must always be estimated or evaluated for individual circumstances. Therefore, a smart Internet of Things (IoT) photovoltaic system enhanced with dust detection and an automatic cleaning process will work as the main function to clean the surface solar photovoltaic according to the established program. Additionally, the installation of the Internet of Things (IoT) in the cleaning systems is to monitor the data produced by solar photovoltaics.

A solar photovoltaic system or solar power system is a power system designed to supply usable solar power by means of photovoltaic. It is made up of a number of components consisting of solar panels to absorb and convert sunlight into electricity, a solar charge controller to control the flow of current from the solar panel to the load, a solar inverter to convert the output from direct to alternating current, a solar battery to charge and discharge the current, and mounting, cabling, and other electrical accessories to make a working system [1][2].

The efficiency and energy produced by the photovoltaic modules are related to the available irradiance and spectral content of the sun. Maintenance improves performance and irradiance through cleaning the surface photovoltaic modules. Cleaning of the photovoltaic panels enables the user of the photovoltaic system to achieve maximum power output by exposing the surface area of the photovoltaic cells to maximum light intensity [3]. Dust formed, if not cleaned from the surface of the Solar Photovoltaic Module, would impede the solar radiation incident on the surface of the photovoltaic panel. Moreover, this affects performance. Thus, to reap the highest amount of solar radiation, photovoltaic panels should always be clean; this is achieved by monitoring the performance of the photovoltaic panel itself by measuring the mass of dust directly on the photovoltaic panel surface before and after cleaning. Finally, by considering some ideas for project implementation, the smart dust detection and automation cleaning of the photovoltaic system is made possible.

It will be mounted with a dust detection system that is sensitive to dust particles and detects the quantity of dust it is. The size of the dust sensors is in compact and thin packages, which allows them to detect reflected light of dust in the air. Then, in the automation cleaning system, various types of end-effectors are used to give more cleanliness to the photovoltaic surface from dust or dirt. Last but not least, dust detection and automation cleaning are supplied by solar energy[4][5]. Table 1 shows the comparison existing system. Overall, the system has different advantages based on the desired use for certain applications.

Table 1 Comparison of the reviewed existing system

Title/ Ref	Software	Advantages
Design and Development of Smart Self-Cleaning Solar Panel System / [6]	Blynx	<ul style="list-style-type: none"> • Improve the efficiency of generating power. • Enhance the durability of solar panels. • The sustainable power source, eco-accommodating and contamination free
Solar Dust Detection System / [7]	Arduino IDE	<ul style="list-style-type: none"> • Provides a method to measure the dust level on the solar panel directly using the tested sensor. • Gain optimum results with the right usage sensor.
A Solar Panel Cleaning Robot Design and Application / [8]	Arduino IDE	<ul style="list-style-type: none"> • Reduces the effect of dusting on the output power of the PV panels. • The system is designed in a short time period and reliable.
Automatic Solar Panel Cleaning System Design / [9]	MATLAB	<ul style="list-style-type: none"> • Low cost designed sensor but gave interesting results. • Improved by adding wireless communication module WIFI.
Sun Tracking Solar Panel with Auto Dust Cleaning System / [10]	Arduino IDE	<ul style="list-style-type: none"> • Build up over time to compromise the panel efficiency and achieve optimum power output. • More convenient and affordable.

2. Proposed Smart Dust Detection Automation Cleaning of Photovoltaics System

Figure 1 shows the proposed block diagram, including the solar photovoltaic system and monitoring system with an IoT system. For the solar photovoltaic system, the water pump is used to pump the water from the water tank to the solar panel through the suitable waterways when the cleaning process is conducted. The tools for the cleaning process, such as wipers, are used to attract water onto the surface of the solar panel after the cleaning process is done while the dc motor is used to move the wiper for the cleaning system. The current sensor is used to measure the amount of voltage produced by a solar photovoltaic panel and can be used to compare before and after cleaning.

For the monitoring system, the ESP32 serves as the system's brain, which supplies power to the load and runs the command. The dust sensors are used to sense particle dust that has accumulated on the surface of

the solar photovoltaic panel. The user uses a Wi-Fi module, such as ESP32, to monitor the value of the solar voltage produced by the solar panel before and after cleaning.

For the IoT system, the Blynk application is applied to this system to monitor the solar voltage through a smartphone only. It will connect to the hotspot and will link with ESP32.

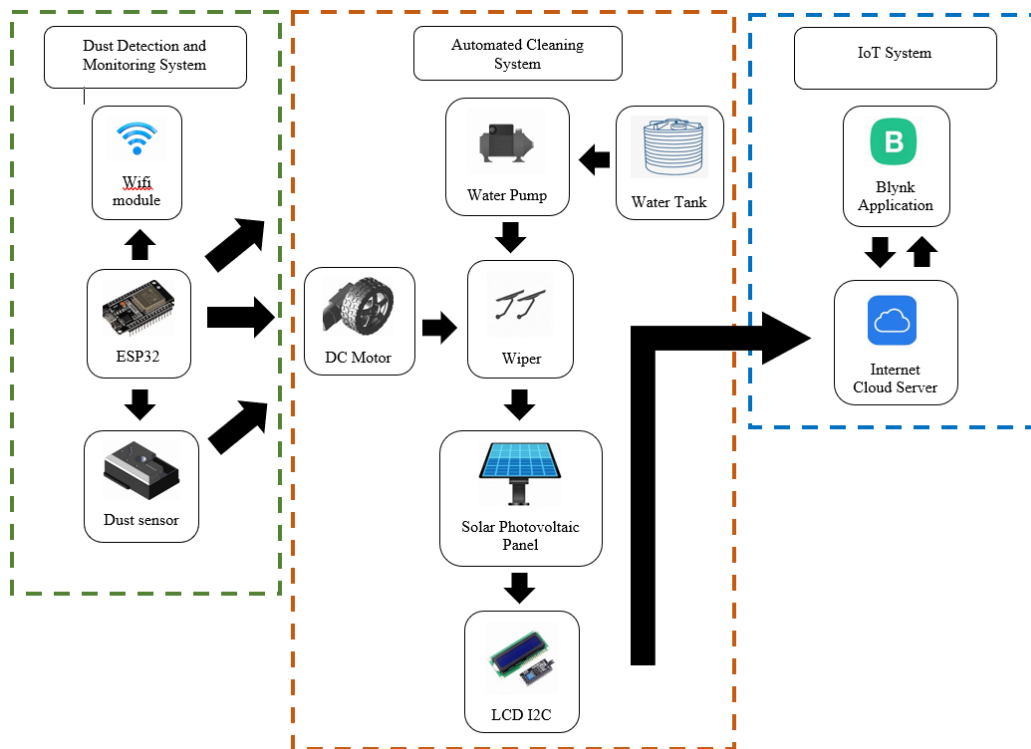


Fig. 1 Block diagram

2.1 Circuit monitoring system

Figure 2 (a) shows the connection monitoring system for the proposed project. Each proposed component is linked according to its function. Thus, the monitoring system consists of the components ESP32, LCD I2C, solar panel, and current sensor, ACS712 20A. After that, the solar panel will produce the solar voltage, and the current sensor will read the value and send the data to the microcontroller, the ESP32. The data will be sent to the LCD via I2C for display of the voltage value. Next, ESP32 is also used to connect the hotspot and send the data to the smartphone through Blynk software. It will show the solar voltage before and after cleaning[11][12].

Figure 2 (b) shows the connection between dust detection and an automated cleaning system for the proposed project. Each proposed component is connected based on its function. Thus, for the connection dust detection and automated cleaning system consists of the components ESP32, dust sensor (GP2Y1014AU0F), two DC motors, motor driver L298n, relay, water pump and adapter 12 V. First thing first, the dust sensor will detect the dust density value. If the dust density is above the set value, the water pump will operate. After that, two DC motors will operate to move forward and backward the wiper on the solar panel. Motor driver L298n is a commonly used dual H-bridge motor driver module that can control the speed and direction of DC motors or control the rotation of the motor. Adapter 12 V as a supply for the DC motor and water pump[13][14].

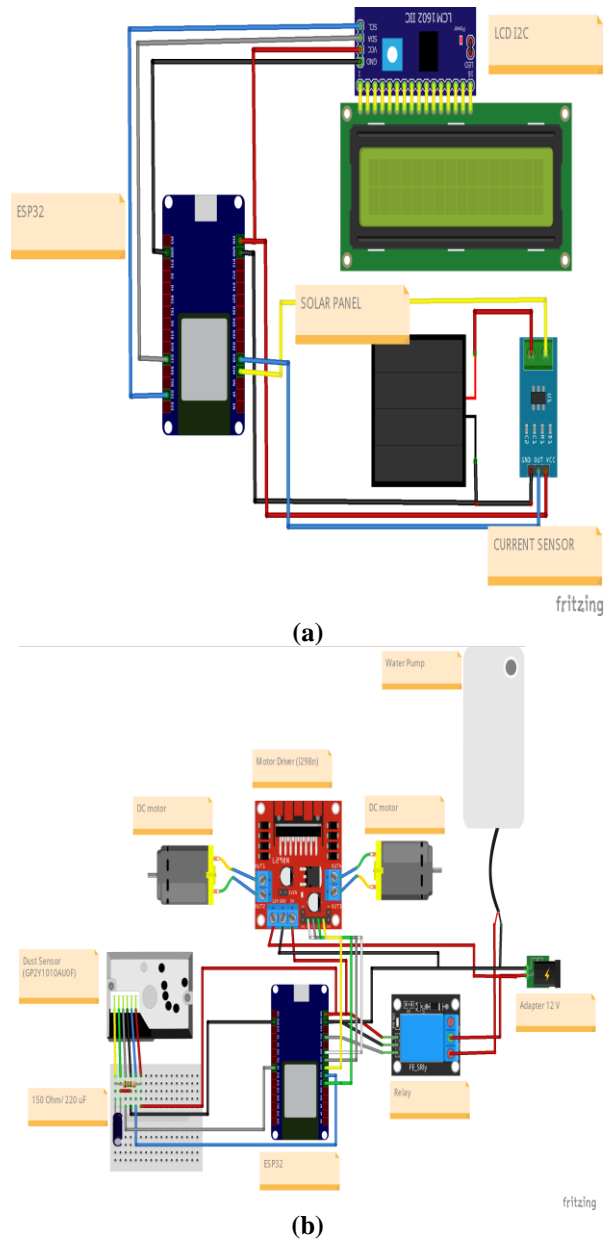


Fig. 2 Overall connection of project (a) Connection of Monitoring System; (b) Connection Dust Detection and Automated Cleaning System

2.2 Determination of solar voltage

In this investigation, the solar has been producing the value of voltage and the value is used for monitoring the system solar panel. The equation to calculate the value of solar voltage is stated in Equations 1 and 2. Equations 3 and 4 portray the dust density equation[15].

$$\frac{\text{Resolution of the ADC}}{\text{System Voltage}} = \frac{\text{ADC Reading}}{\text{Analog Voltage Measured}} \tag{1}$$

$$\text{Solar voltage, } V_{out} = \text{measure voltage} \times (5.0 \times 1024) \tag{2}$$

$$\text{Voltage, } V_{out} = \text{measure voltage} \times (5.0 \times 1024) \tag{3}$$

$$\text{Dust density} = 170 \times \text{voltage} - 0.1 \tag{4}$$

3. Result and discussion

This prototype was created to be a smart dust detection and automated cleaning system by using an electronic microcontroller such as ESP32 with embedded Internet of Things (IoT) through Blynk. The design of smart dust detection and automated cleaning system has been made by using ESP32, motor driver, two DC motors, dust sensor level, water pump, relay and LCD I2C. Figure 4.14 shows the full circuit of smart dust detection and automated cleaning systems with solar panels. All the components get the supply from ESP32, while the motor driver and water pump are connected to a 12 V adapter supply. Figure 3 shows a view of the smart dust detection and automation cleaning PV system.

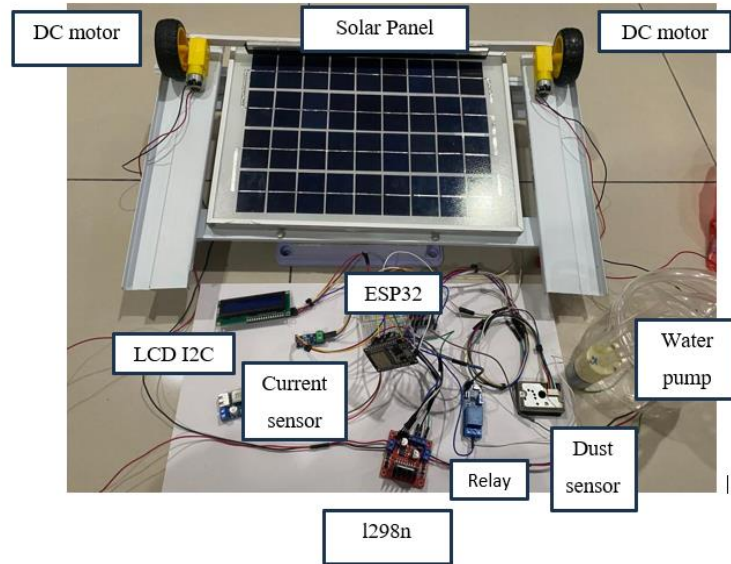


Fig 3. Prototype of project

Figure 4(a) shows the graph of time vs. voltage (V). From the graph, it can be seen that the maximum value of the voltage is 13.49 V at peak hours, which is 1200. Besides, figure 3 (b) shows the graph time vs. current (A), and from the graph, it can be seen that the maximum value of current is 0.66 A at peak hours, which is 1200.

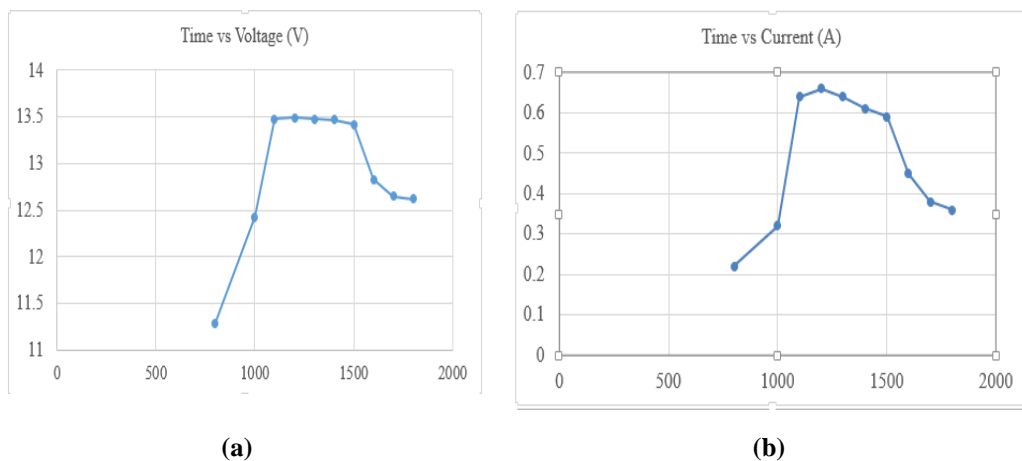


Fig. 4 Graph of project (a) Time vs voltage; (b) Time vs current

Figure 5 (a) shows the coding of the condition for the dust detection system where if dust density is above the value set, the automated cleaning system will operate sequence based on the code setup. Before that, the value of dust density is obtained from the voltage measure, where the voltage measure is multiplied by the amount of

5.0 divided by 1024. The amount will be used to calculate dust density, where 0.17 is multiplied by the amount and subtracted from 0.1.

Figure 5 (b) shows the coding for the automated cleaning system. After the dust sensor detects the particle dust density with the value set, the water pump will operate based on the period setup. After that, the motor will operate and move forward and reverse to the base until the period setup finishes. When the motor is already back to the base, the automated cleaning system is already done and the dust sensor will continue to detect the dust density. If the dust density value is above the setup value, the system will run again.

Figure 5 (c) shows the serial monitor recording the value of the dust density level and recording the process of the system flow. When the dust sensor detects a value above 3.0, the serial monitor will show the device, such as a water pump or DC motor, turning on and off according to the coding setup.

Figure 6 shows the water pump is in ON condition where the dust sensor detects above 3.0. After the water pump is ON for around three minutes, it will turn OFF, and the motor will start ON where by moving forward to wipe the water using the wiper. Figure 4.10 shows the motor moving forward to wipe the water on the solar panel by using a wiper. After wiping the water until the end of the solar panel, it will stop instantaneously and will move back to the base. Figure 4.11 shows the motor moving back to the base after finishing wiping the water.

```

104
105 | calcVoltage = voMeasured*(5.0/1024);
106 | dustDensity = 0.17*calcVoltage-0.1;
107 | Serial.println(dustDensity);
108 | if ( dustDensity < 0)
109 | {
110 |   dustDensity = 0.00;
111 | }
112
113 | if(dustDensity >3.0) // set base on ur need
114 | {
115 |
116 |   if(cleanRun)
117 |   {
118 |     clean(); // start cleaning
119 |   }

```

```

// 3. Star water pump
digitalWrite(water,LOW);
Serial.println("water on");
delay(3000);
digitalWrite(water,HIGH); // Off water pump
Serial.println("water off");
// 1. Start robot
digitalWrite(motorbPin1, HIGH);
digitalWrite(motorbPin2, HIGH);
Serial.println("motor1 on");
delay(500); // set tempoh motor gerak
// 2. Off motor
digitalWrite(motorbPin1, LOW);
digitalWrite(motorbPin2, LOW);
Serial.println("motor1 off");
delay(500); // break jap

// 4. Return to base
digitalWrite(motorfPin1, HIGH);
digitalWrite(motorfPin2, HIGH);
Serial.println("motor2 on");
delay(500); // set tempoh motor gerak
digitalWrite(motorfPin1, LOW);
digitalWrite(motorfPin2, LOW);
Serial.println("motor2 off");
delay(500); // break jap

```

(a)

(b)

```

COM8
16:36:28.365 -> 0.07
16:36:28.637 -> 0.15
16:36:28.942 -> 0.06
16:36:29.212 -> 0.10
16:36:29.516 -> 0.07
16:36:29.789 -> 0.21
16:36:30.091 -> 3.30
16:36:30.125 -> water on
16:36:33.124 -> water off
16:36:33.124 -> motor1 on
16:36:33.602 -> motor1 off
16:36:34.112 -> motor2 on
16:36:34.619 -> motor2 off
16:36:35.395 -> 3.30
16:36:35.430 -> water on
16:36:38.432 -> water off

```

(c)

Fig. 5 Coding optimization(a) Dust density above value; (b) Automated cleaning (c) Data of cleaning process.



Fig. 6 Coding optimization and cleaning process(a) Data of cleaning process; (b) Water flow to panel

Conclusion

The integration of cleaning technologies for photovoltaic (PV) solar panels, particularly through the use of Internet of Things (IoT) systems, significantly enhances power generation efficiency and panel durability by addressing dust accumulation that hampers energy output. The development of smart dust detection systems allows for real-time monitoring of dust levels, enabling faster analysis and proactive maintenance, which leads to improved performance and cost savings. Additionally, automated cleaning systems equipped with dust sensors can efficiently remove dust particles without manual intervention, further increasing energy output and sustainability. IoT-based monitoring solutions provide critical data on solar voltage and dust levels, optimizing the overall performance and longevity of solar installations. This technological advancement supports the broader adoption of clean, renewable energy sources by ensuring that solar panels operate at their maximum potential while minimizing downtime and maintenance costs[16][17].

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

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