Wireless Enabled Solar Panel Monitoring System

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*Abstract*—This paper introduces a Wireless Enabled Solar Panel Cleaning and Monitoring System, utilizing LDR sensors and an Arduino-controlled brush mechanism for efficient solar energy production. The system autonomously detects and removes dust or debris accumulation, optimizing energy output while minimizing panel damage. Real-time monitoring ensures proactive maintenance, enhancing sustainability and performance of solar energy systems.

Keywords—Solar Panel, Cleaning, Wireless, Bluetooth Based

# Introduction

# In recent decades, power generation from photovoltaic (PV) sources has witnessed a remarkable surge, progressively establishing itself as a primary contributor to our energy landscape. Concurrently, research endeavors have intensified, striving to augment the efficiency of solar panels, a cornerstone of this renewable energy ecosystem. Efficiency, denoting the ratio of incoming solar energy to achievable output power, has soared, culminating in a current pinnacle of 44.7%. Yet, the pursuit of efficiency transcends solitary panel enhancements, extending its gaze to the holistic solar infrastructure.

Within this paradigm, the focus extends to the ancillary equipment integral to PV systems, notably the power inverters responsible for converting direct current (DC) from panels into alternating current (AC) for grid integration. Acknowledging that losses at any juncture impede overall system efficiency, recent strides have propelled the domain of PV inverters into distributed architectures. This evolution, epitomized by the deployment of small-scale inverters tethered to individual panels, heralds a paradigm shift. Local optimization empowers each panel to realize its maximum potential, fostering heightened energy yield and facilitating nuanced performance monitoring.

## Objective

First, confirm that you have the correct template for your paper size. Despite these advancements, the efficacy of solar panels encounters a formidable adversary in the form of dust and debris accumulation. This encumbrance disrupts sunlight absorption, precipitating diminished output and compromised efficiency. Recognizing the imperative of regular maintenance, this report delineates the conceptualization and realization of a Wireless-Enabled Solar Panel Cleaning and Real-Time Monitoring System, underpinned by Arduino microcontroller technology.

Central to this innovation is its dual-pronged functionality. Firstly, the system automates the cleaning process, ensuring the perennial pristine condition requisite for optimal performance. Secondly, it integrates real-time monitoring capabilities, affording stakeholders comprehensive insights into power generation parameters. By preemptively addressing the menace of dust accumulation and furnishing a framework for proactive maintenance, this system epitomizes a watershed moment in solar panel management, promising to augment efficiency and prolong operational lifespan.

## Existing Method

Within the expansive realm of solar energy systems, the pursuit of optimal efficiency and productivity is incessantly challenged by an omnipresent adversary: the accumulation of dust and debris upon the surfaces of solar panels. This encroachment forms a formidable impediment, obstructing the panels' capacity to harness sunlight efficiently. Consequently, a discernible decline in output power and overall efficiency ensues, undermining the system's ability to realize its full potential.

In response to this exigent predicament, the need arises for methodologies dedicated to the restoration and preservation of optimal performance levels of solar panels through effective cleansing. One prominent approach entails manual cleansing procedures, employing rudimentary tools such as water and soft bristle brushes. While this traditional method has demonstrated efficacy in removing surface impurities, its utility is hampered by an array of limitations.

Foremost among these limitations is the labor-intensive nature of the manual cleaning process, exacting a toll on human resources and time allocation. The arduous endeavor of manually scrubbing each panel surface demands significant human effort and consumes invaluable time resources. Moreover, the manual approach necessitates the procurement of specialized equipment and the provision of extensive training for operators to ensure proficient execution. This prerequisite for specialized resources further compounds the logistical and financial burdens associated with manual cleaning methodologies.

Furthermore, the manual cleaning process is plagued by inefficiencies stemming from its inherently time-consuming nature. The intricate sequence of scrubbing, rinsing, and drying each panel surface prolongs the cleaning cycle, resulting in substantial downtime for the solar panel system. This intermittent interruption to system operation not only disrupts energy generation but also engenders a ripple effect on overall productivity and operational continuity.

# Drawbacks of this existing method

Manual cleaning methods, constituting the predominant approach for maintaining solar panel cleanliness, rely heavily on human intervention and physical labor to rid panels of dust and debris. However, these methods inherently harbor challenges and inefficiencies, predominantly stemming from their labor-intensive nature, which significantly impacts system performance. The execution of manual cleaning necessitates the deployment of human resources, thereby escalating operational costs and resource allocation. Moreover, the proficiency in manual cleaning demands specialized training for personnel, amplifying the complexity and financial burden of the process. Consequently, the combination of labor deployment and training prerequisites exacerbates operational costs, underscoring the inherent drawbacks of manual cleaning methodologies.

## Proposed System

Our innovative Wireless-Enabled Solar Panel Monitoring System represents a pioneering approach to sustaining the efficiency and efficacy of solar energy infrastructures. Through the integration of Light Dependent Resistor (LDR) sensors and an Arduino-controlled brush mechanism, our system delivers a sophisticated solution to counteract the challenges posed by dust and debris accumulation on solar panels.

At the core of our system lies the strategic placement of LDR sensors, continuously monitoring ambient light intensity alongside solar panel output voltage. This real-time monitoring empowers the system to promptly identify instances of diminished energy production attributable to dirt accumulation during periods of high ambient light. Upon detection of such conditions, the Arduino controller orchestrates the commencement of the cleaning process.

The cleaning mechanism, orchestrated by Arduino-controlled motors, employs a methodical brush system to traverse the surface of solar panels systematically. This meticulous approach effectively dislodges dust, dirt, and other contaminants, ensuring thorough cleansing while safeguarding panel integrity.

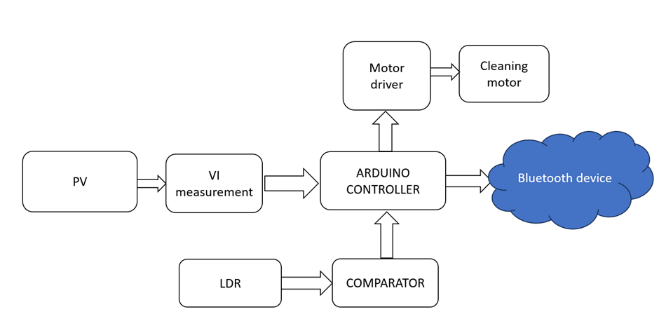
By automating cleaning protocols based on real-time data insights, our system yields several notable advantages. Firstly, it obviates the necessity for manual inspection and cleaning, thereby curtailing labor costs and augmenting operational efficiency. Secondly, by preemptively addressing dirt accumulation, the system optimizes energy generation efficiency, culminating in heightened overall output from solar installations. Furthermore, the system's autonomous functionality guarantees consistent cleaning schedules, further enhancing performance and minimizing downtime.

In summary, our Wireless-Enabled Solar Panel Monitoring and Cleaning System epitomizes a cost-effective, reliable, and sustainable solution for preserving the efficiency and functionality of solar energy frameworks. Through the amalgamation of advanced technologies such as LDR sensors and Arduino control, this system proffers a proactive maintenance paradigm, thereby fostering the widespread embrace and triumph of solar energy as a pristine and renewable power source. This pioneering system amalgamates several pivotal components to engender an efficient and self-reliant cleaning mechanism for solar panels.

## Advantages

* The proposed system presents a paradigm shift in the maintenance of solar panels, leveraging real-time data analysis to autonomously initiate cleaning procedures.
* By integrating sensors capable of monitoring ambient conditions and panel performance, the system detects instances of decreased energy production caused by dust or debris accumulation, ensuring timely and precise cleaning without manual intervention.
* This innovative approach not only streamlines maintenance processes but also significantly reduces reliance on manual labor, resulting in substantial cost savings and making solar energy more economically viable.
* Overall, the proposed system represents a comprehensive solution that optimizes the efficiency, economic viability, and long-term sustainability of solar energy installations in the global renewable energy landscape.

## Block Diagram



The proposed solar panel cleaning system operates seamlessly, ensuring the optimal performance and prolonged lifespan of solar energy installations. Employing Light Dependent Resistor (LDR) sensors for continuous monitoring, the system remains vigilant, assessing real-time ambient light intensity and solar panel output voltage. Upon detection of high ambient light intensity coupled with low panel output voltage—a clear indicator of dirt accumulation—the system swiftly activates. Driven by an Arduino controller, the cleaning mechanism orchestrates the precise movement of brushes across the panel surfaces, effectively dislodging dust and debris without jeopardizing panel integrity.

This meticulous control guarantees thorough cleaning while safeguarding panel health. Revolutionizing maintenance practices, the Arduino-controlled brush mechanism responds proactively to dirt accumulation based on real-time data, obviating the need for labor-intensive manual cleaning and minimizing system downtime.

The system's autonomous operation ensures consistent cleaning schedules, optimizing energy generation efficiency and maximizing overall solar installation output. In summary, the proposed solar panel cleaning system epitomizes a cost-effective, reliable, and sustainable solution for sustaining peak performance in solar energy systems. Seamlessly integrating advanced technologies like LDR sensors and Arduino control, this system offers a proactive maintenance approach, enhancing the viability and attractiveness of solar energy as a clean and renewable power source.

# Hardware Details and Hardware Description

Most electronic circuits require DC voltage sources or power supplies. If the electronic device is to be portable, then one or more batteries are usually needed to provide the DC voltage required by electronic circuits. But batteries have a limited life span and cannot be recharged. The solution is to convert the alternating current lose hold line voltage to a DC voltage source.

## Power Supply

Most electronic circuits require DC voltage sources or power supplies. If the electronic device is to be portable, then one or more batteries are usually needed to provide the DC voltage required by electronic circuits. But batteries have a limited life span and cannot be recharged. The solution is to convert the alternating current lose hold line voltage to a DC voltage source.

### Transformer: Steps the household line voltage up or down as required

### Rectifier: Converts ac voltage into dc voltage.

### Filter: Smooth the pulsating DC voltage to a varying DC voltage.

### Regulator: Fix the output voltage to constant value.

## Transformer

A Transformer is an electrical device that takes electricity of one voltage and changes it into another voltage. In AC circuits, AC voltage, current and waveform can be transformed with the help of Transformers. Transformer plays an important role in electronic equipment. AC and DC voltage in Power supply equipment are almost achieved by transformer’s transformation and commutation. Figure 4.1 shows the Transformer.

Basically, a Transformer changes electricity from high to low voltage or low to high voltage using two properties of electricity. In an electric circuit, there is magnetism around it. Second, whenever a magnetic field changes (by moving or by by changing strength) a voltage is made. A Transformer takes in electricity at a higher voltage and lets it run through lots of coils wound around an iron core. “. A single-phase Transformer can operate to either increase or decrease the voltage applied to the primary winding. Because the current is alternating, the magnetism in the core is also alternating. Also around the core is an output wire with fewer coils. The magnetism changing back and forth makes a current in the wire. Having fewer coils means less voltage. When it is used to “decrease” the voltage on the secondary winding with respect to the primary it is called a Step-down Transformer. When a Transformer is used to “increase” the voltage on its secondary winding with respect to the primary, it is called a Step-up Transformer.

However, a third condition exists in which a transformer produces the same voltage on its secondary as is applied to its primary winding. In other words, its output is identical with respect to input. This type of Transformer is called an “Impedance Transformer” and is mainly used for impedance matching or the isolation of adjoining electrical circuits.

## Arduino UNO Controller

#### The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Uno differs from all preceding boards in that it does not use the FRDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

#### Some of it’s features are:

#### Microcontroller : ATmega328

#### Operating Voltage : 5V

#### Input Voltage (recommended) : 7-12V

#### Input Voltage (limits) : 6-20V

#### Digital I/O Pins : 14 (of which 6 provide PWM output)Analog Input Pins : 6

#### DC Current per I/O Pin : 40mA

#### DC Current for 3.3V Pin : 50mA

#### Flash Memory : 32 KB of which 0.5 KB used by bootloader.

#### SRAM : 2KB

#### EEPROM : 1KB

#### Clock Speed : 16 Mhz

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board’s power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The power pins are as follows:

* VIN. The input voltage to the Arduino board when it’s using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
* 5V. The regulated power supply used to power the microcontroller and other components o the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated5V supply.
* 3V3. A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50mA.
* GND. Ground pins.

#### Characteristics

The maximum length and width of the Uno PCB are 2.7 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Three screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16’’), not an even multiple of the 100 mil spacing of the other pins.

#### Rectifier

A rectifier circuit converts an AC voltage into a pulsating DC voltage. This is accomplished by using one or more diodes because diodes conduct current in only one direction.

The transformer (T1) isolates the household voltage and also steps down the household voltage to a more useful voltage level. The diode lets current flow into the load in only one direction. The load current is unidirectional; therefore, it has a significant dc component (or average value).When V2 is positive, diode D1 conducts and VL=V2. When V2 is negative, diode D1 blocks the current flow and VL=0volts. The load voltage consists of dc voltage along with ripple voltage. In a half-wave rectifier circuit, the ripple component is larger than the DC component, which is undesirable.

#### Light Dependent Resistor

It has been observed that lowering the initial conductivity of a semiconductor higher is its photosensitive property. That is why photo resistors are prepared from lightly doped semiconductors.

Photo resistors are generally prepared either by coating the layer of power photosensitive material or by depositing a semiconductor film on an insulating base. Silicon is usually preferred for this purpose. The semiconductor deposited on an Insulating substance constitutes a unit, which is placed either, a metallic or plastic case whose top surface is covered with glass. The glass cover of the compact unit allows light rays to reach the semiconductor-coated surface accordingly the resistance changes. They are usually made in the form of cadmium sulphur discs is provided with two tinned copper connecting leads. Rating and performance of the devices shown in the figure, arc characteristics by the value of current flowing through the device at a given voltage and the amount of light flux.

The LDR behaves like a switch. In the presence of light it poses a very little (almost negligible) resistance in the circuit giving the ON state, Whereas in darkness it poses a very high resistance which causes almost no flow of current thus resulting in then OFF state of the switch. Hence, the device acts like an automatic switch who’s ON and OFF states are dependent on the total Illumination and dark conditions respectively.

#### Gear Motor

A geared motor is a component whose mechanism adjusts the speed of the motor, leading them to operate at a certain speed. geared motor have the ability to deliver high torque at low speeds, as the gearhead functions as a torque multiplier and can allow small motors to generate higher speeds. A geared motor can also be defined as a gear reducer because essentially, it is a combination of a speed reducer with a motor typically functioning as a gearbox, to reduce speed making more torque available. geared motor can be classified based on the motor they are paired with, including bevel, helical, hypoid, spur and worm gears. Each of these gears have advantages and disadvantages. For example, helical gears possess more torque capacity than spur gears, hence, generating less noise. Worm gears work efficiently in the low torque angel and are good for high speed reductions.

#### L298N Motor Driver Module

L298N module is a high voltage, high current dual full-bridge motor driver module for controlling DC motor and stepper motor. It can control both the speed and rotation direction of two DC motors. This module consists of an L298 dual-channel H-Bridge motor driver IC. This module uses two techniques for the control speed and rotation direction of the DC motors. These are PWM – For controlling the speed and H-Bridge For controlling rotation direction. These modules can control two DC motor or one stepper motor at the same time.

This motor driver module consists of two main key components, these are L298 motor driver IC and a 78M05 5V regulator.

L298 is a high voltage, high current dual full-bridge motor driver IC. It accepts standard TTL logic levels (Control Logic) and controls inductive loads such as relays, solenoids, DC and Stepper motors. This is a 15 pin IC. According to the L298 datasheet, its operating voltage is +5 to +46V, and the maximum current allowed to draw through each output 3A. This IC has two enable inputs, these are provided to enable or disable the device independently of the input signals.

A black color heat sink is attached to the L298 IC of the module. A heat sink is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant.

The module has an on-board 78M05 5V Voltage regulator. This Voltage regulator will be performed only when the 5V Enable jumper is placed. When the power supply is less than or equal to 12V, then the internal circuitry will be powered by the voltage regulator, and the 5V pin can be used as an output pin to power the microcontroller or other circuitry (sensor).

The jumper should not be placed when the power supply is greater than 12V and separate 5V should be given through 5V terminal to power the internal circuitry.

This module uses two techniques for the control speed and rotation direction of the DC motors. These are H-Bridge For controlling rotation direction and PWM – For controlling the speed.

L298n motor driver module uses the H-Bridge technique to control the direction of rotation of a DC motor. In this technique, H-Bridge controlled DC motor rotating direction by changing the polarity of its input voltage.

An H-Bridge circuit contains four switching elements, like transistors (BJT or MOSFET), with the motor at the center forming an H-like configuration. Input IN1, IN2, IN3, and IN4 pins actually control the switches of the H-Bridge circuit inside L298N IC.

We can change the direction of the current flow by activating two particular switches at the same time, this way we can change the rotation direction of the motor.

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##### Results and Discussion

The novel Wireless Enabled Solar Panel Monitoring and Cleaning System presented in this paper demonstrated promising results in maintaining optimal energy production efficiency through automated dust and debris removal. The integration of Light Dependent Resistor (LDR) sensors, an Arduino-controlled brush mechanism, and Bluetooth technology for power generation monitoring proved to be effective in enhancing the reliability and performance of solar installations.

##### The real-time monitoring capability provided by LDR sensors enabled the system to autonomously detect dust or debris accumulation on the surface of solar panels. By continuously measuring ambient light intensity and the output voltage of the panels, the system could accurately identify instances of reduced energy production due to dirt buildup. This proactive approach to maintenance ensured that cleaning actions were initiated promptly, minimizing the impact of contamination on energy generation efficiency.

The Arduino-controlled brush mechanism facilitated precise and controlled cleaning operations, effectively removing dust, dirt, and other contaminants from the surface of the solar panels. The motors, controlled by the Arduino microcontroller, enabled smooth and uniform movement of the brush mechanism across the panel surface, ensuring thorough cleaning while minimizing the risk of damage to the panels.

Furthermore, the integration of Bluetooth technology for power generation monitoring provided an additional layer of functionality, allowing users to remotely monitor the energy output of the solar panels. This feature enhanced the system's usability and convenience, enabling users to track performance metrics and identify potential issues promptly.

Overall, the proposed solar panel cleaning system offers a proactive and efficient approach to maintenance, ensuring optimal energy generation efficiency and prolonging the lifespan of solar installations. By automating the cleaning process based on real-time monitoring of panel performance, the system reduces the reliance on manual intervention, minimizing downtime and maximizing energy output. Moreover, the scalability and versatility of the system make it suitable for various applications, ranging from residential rooftop installations to large-scale solar farms, contributing to the advancement of sustainable energy production.

In conclusion, the proposed Wireless Enabled Solar Panel Monitoring and Cleaning System, incorporating a compressor, Arduino microcontroller, and relay module, offers a comprehensive and innovative solution to address the persistent challenge of maintaining optimal solar panel performance. By using compressed air to dislodge and remove contaminants, it provides an eco-friendly, cost-effective, and energy-efficient method for cleaning solar panels. The system's autonomous operation, real-time monitoring, and remote control capabilities make it a user-friendly and responsive solution. Furthermore, the sustainability it promotes by extending the lifespan of solar 3panels and reducing the need for additional units underscores its significance in advancing renewable energy technologies. With this technology, we can ensure that solar energy systems continue to deliver clean and efficient power for the long term, supporting a more sustainable and environmentally responsible energy future.

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