



Designing a Google Voice-Based Solar Panel Cleaner Control System

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Abstract— Current solar panel maintenance often involves manual, rooftop fieldwork, which introduces significant fall-from-height risks and occupational hazards. To address this, this research investigates the integration of the Internet of Things (IoT) to streamline and enhance operational efficiency. The goal is to develop an IoT-enabled solution for user-driven routine maintenance that can significantly mitigate occupational hazards and reduce maintenance duration. This system is designed to optimize the long-term energy yield of solar panels by preventing the typical efficiency decline caused by neglected upkeep. The study employs a prototype development method (literature review, construction model design, and control system development). The final system leverages common consumer-grade terminal devices (smartphones, laptops) to provide a ubiquitous, real-time control interface, allowing users to manage the system remotely via a stable network connection.

Keywords: solar panel cleaner, IoT, control system

Article submitted 2025-09-29.

Resubmitted 2025-10-18.

Final acceptance 2025-10-19.

Final version published as submitted by the authors.

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Citation Document:

Tessal, D., Marzal, J., Triantini, D., Wirasapta, A. H., Fikri, M. K., Saputra, A. R. T., & Mishi, S. S. (2025). Designing a Google Voice-Based Solar Panel Cleaner Control System. *Jurnal Edukasi Elektro*, 9(2), 202–213. <https://doi.org/10.21831/jee.v9i2.90041>

1 Introduction

Pollutants can cause a large voltage drop when compared to smaller dust intensity levels. With a dust intensity level of 0.30 mg/m^3 has a voltage value of 12.03 V and the voltage after cleaning gets a value of 13.51 V, the voltage difference is 1.48V. while the smallest dust intensity value of 0.04 mg/m^3 has a voltage value of 8.92 V and after being cleaned by the tool gets a voltage value of 9.09 V which means it has a difference of 0.17 V [1].

The increasing global deployment of solar panel systems necessitates a critical focus on sustaining optimal performance. A primary inhibitor of efficiency is surface soiling—the accumulation of dust, dirt, pollen, and other environmental contaminants on the solar panel surface. This deposition

directly contributes to significant power loss (depending on geographic location and climate), critically impacting the return on investment for solar panel installations [2], [3], [4]. To effectively mitigate this substantial power degradation, regular and systematic maintenance, primarily through periodic cleaning, is deemed essential for all operational solar panel.

Conventional cleaning uses a manual application of water and an absorbent medium to remove surface contaminants. While straightforward and low-cost, this method's efficacy is strictly limited by physical accessibility and safety regulation [5], [6], [7]. When panels are on rooftops or other elevated structures, the need for personnel to ascend to height introduces significant operational complexity and severe occupational safety hazards [8]. This inherent risk severely restricts the feasibility of routine manual cleaning, often causing prolonged cleaning intervals, continued efficiency losses, and maintenance schedule non-compliance. This gap highlights the necessity for automated, remote solutions to ensure continuous, safe, and effective solar panel system maintenance.

Given the constraints and safety risks of manual maintenance, the Internet of Things (IoT) represents a critical paradigm shift toward more effective and efficient solar panel upkeep [9], [10], [11]. Integrating sensors, microcontrollers, and cloud platforms enables the deployment of intelligent, networked systems that allow for remote monitoring and actuation [12]. This transforms routine maintenance from a reactive, labor-intensive task into a proactive, automated process. This research specifically investigates integrating an automated cleaning control system with network connectivity to mitigate the challenges of manual intervention and promote optimal solar energy conversion.

Entitled, "Designing a Google Voice-Based Solar Panel Cleaner Control System," this study proposes a system where a microcontroller (MCU) manages the mechanical cleaning mechanism and provides the necessary network interface. The MCU functions as the edge device, allowing the entire cleaning system to be remotely actuated via a high-level, accessible interface. The core innovation lies in enabling control specifically through Google Voice commands. This voice-based interaction simplifies the user experience by offering an intuitive, hands-free method of operation, which is highly desirable in modern smart home and industrial IoT environments [13], [14]. This design enables the control system to be safely activated without requiring a hazardous physical presence on elevated structures, thereby dramatically improving the ease and regularity of maintenance and securing the long-term efficiency of the photovoltaic installation.

2 Method

This investigation adopts a prototype development design. The research procedure is segmented into several key stages: preliminary literature analysis, the structural and control system design, the practical implementation of the control system, tool integration and assembly, a rigorous functional assessment, and a concluding results evaluation. Figure 1 presents the systematic structure of this methodology for creating the tool prototype.

Arduino was selected as the core microcontroller for this research due to its superior ease of use and broad suitability for both novice and professional applications [15]. The platform features a straightforward programming interface, extensive documentation, and a large, active community that readily shares project examples and technical support. Furthermore, Arduino's open-source nature allows for tailored modification, and it supports a wide array of microcontrollers and peripheral modules [16]. Its affordability and seamless integration with diverse sensors and devices make Arduino the ideal choice for rapid prototyping and micro-controller-based research development.

Google Voice was chosen for the speech recognition interface primarily due to its high recognition accuracy and comprehensive multi-language support, including Bahasa Indonesia [17]. Google's underlying speech processing technology, powered by continually updated artificial intelligence, ensures robust recognition across varied accents and intonations. Crucially, Google Voice is accessible free of charge and maintains stable performance across both Android and web-based platforms, offering a practical and cost-efficient solution for voice-based applications. The service's strong integration within the broader Google ecosystem guarantees easy implementation and reliable operation across different network conditions [18].

The data analysis primarily focused on validating user voice control functionality mediated through Google Assistant via a smart device interface. The objective of this analytical phase was to assess system performance and diagnose operational anomalies within the device. The testing protocol was rigorously structured into six distinct phases: voice command validation, wireless communication range assessment (distance testing), web and application functionality verification, and the measurement of key performance indicators—specifically, voltage, current, and power output—both prior to and following the cleaning procedure.

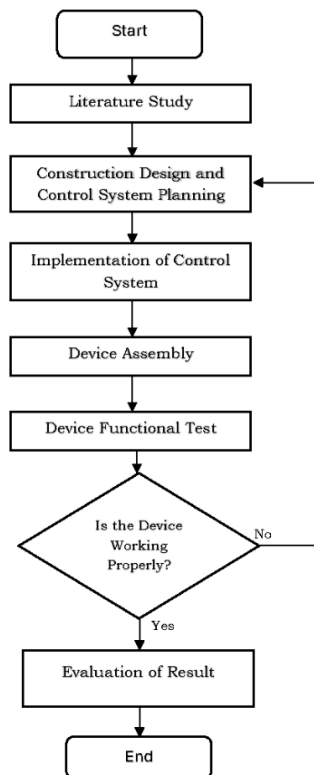


Figure 1. Flowchart of research

2.1 Architecture System

The system block diagram and the accompanying flowchart presented in Figure 2 illustrate the software design architecture developed to ensure the precise and predetermined operation of the control system. The foundational programming environment utilized for this design is the Arduino Integrated Development Environment (IDE).

This software framework serves several critical functions: it uploads the operational program to the microcontroller (specifically the NodeMCU ESP8266, as detailed in the flowchart), issues control commands to the connected system hardware, and provides the necessary database code for seamless interaction and control of smart home devices (via Google Assistant).

As depicted in the flowchart, the system initiates operation by establishing a stable Wi-Fi connection. Once connected, the system is designed to respond to three distinct control inputs simultaneously: automated time-based commands (e.g., scheduled activation at 6:00 am), direct voice commands (processed via Google Assistant), and manual web-based commands. All successful commands converge at the NodeMCU ESP8266 microcontroller, which then triggers the final ON/OFF actuation of the Wiper or Water Pump mechanism to execute the cleaning cycle.

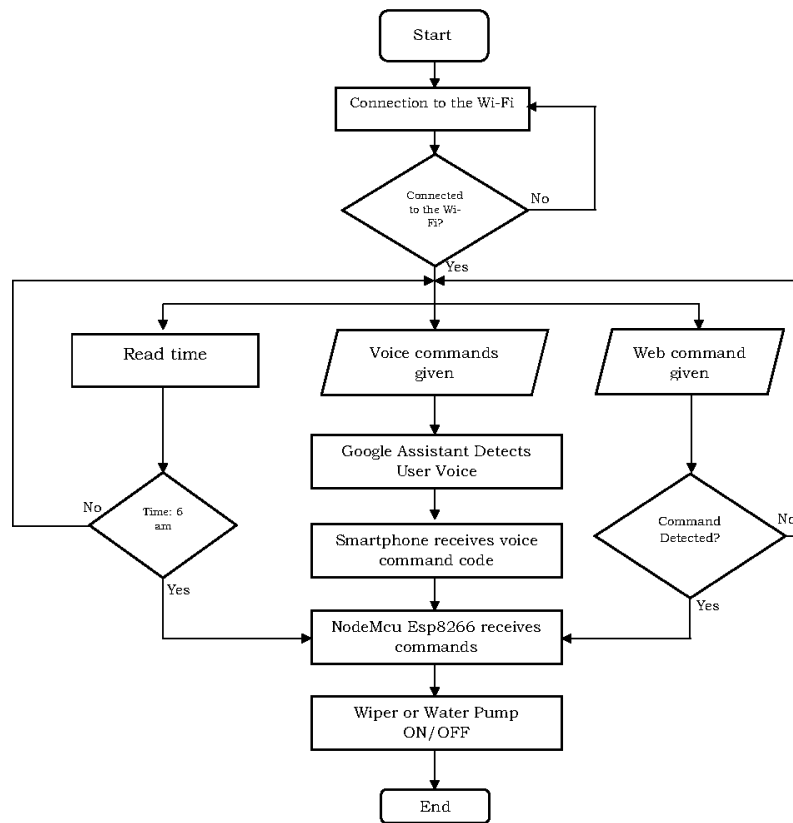


Figure 2. Flowchart of solar panel cleaning control system algorithm

2.2 Construction Design and Control System Planning

Figure 3 illustrates the architectural design of the prototype, which is constructed as a Smart Home-integrated model designed for voice-command operation. The physical structure is enclosed within a portable casing, fabricated primarily from wood, to demonstrate a scaled-down residential application. Internally, the prototype features a dedicated section of foam material to securely house the microcontroller components and serve as the water reservoir required for the cleaning process.

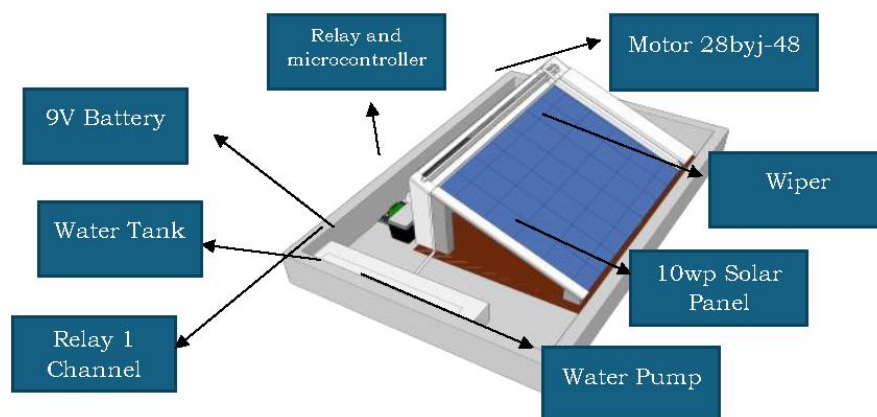


Figure 3. Miniature construction model of device

The system utilizes a 10 Wp solar panel as the cleaning target. A wiper mechanism, powered by a 28BYJ-48 motor, is installed on the panel to execute horizontal cleaning movements. A flexible hose, attached to the wiper, delivers water from an internal reservoir. Both the water pump and the motor are precisely regulated by a 1-Channel Relay and the microcontroller to ensure accurate, automated operation. The entire unit is powered by a 9V battery. This design integrates all cleaning components into a single, fully controllable smart system.

Figure 4 presents the prototype of the automated solar panel cleaning system. The structural casing is constructed from Meranti wood, while a sheet of styrofoam is strategically utilized internally to provide a stable, insulating base for all electronic and mechanical components.



Figure 4. Mechanical design results

The 10 Wp solar panel is mounted within a custom-designed aluminum frame. This frame is essential for defining the precise travel limits and range of motion of the cleaning mechanism, ensuring effective panel coverage. The wiper mechanism uses a foam pad as the primary medium for physically removing surface pollutants. Additionally, the wiper integrates a water delivery hose connected to a pump. This setup allows the panel surface to be moistened simultaneously during the sweeping action, which significantly enhances the efficiency of pollutant removal.

The motion of the wiper is powered by a 28BYJ-48 motor. This specific motor was selected for its accessibility and demonstrated performance suitability for a prototype of this scale, offering sufficient precision for the required horizontal movement.

Ultimately, this automated wiper system is designed to serve as a direct replacement for hazardous manual panel cleaning procedures. By integrating the wiper, water pump, and control system with the Internet of Things (IoT), users gain remote and streamlined control over the maintenance process. This automation effectively eliminates the need for manual water application and physically reaching the panels, thereby significantly improving maintenance efficiency and mitigating the occupational safety risks associated with elevated work.

2.3 Implementation in Hardware Device System

Figure 5 presents the complete hardware schematic, detailing the interconnections and configuration of all system components. To achieve the desired functionality of the Internet of Things (IoT)-based control system, a robust software program is critically required. This program is specifically designed to be uploaded onto the NodeMCU microcontroller, enabling it to interpret incoming network commands and subsequently execute the necessary operational directives for the device.

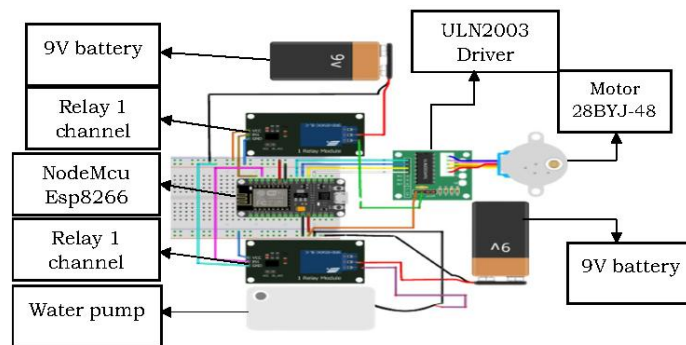


Figure 5. Device schematic

Following the successful upload of the program to the ESP8266 NodeMCU, the device requires online configuration to enable real-time control. This process commences with the user logging into the Sinric Pro platform as shown in Figure 6a. Subsequently, the user navigates to the device management section to register the new hardware instance as shown in Figure 6b. The device parameters are then configured according to the desired operational specifications as shown in Figure 7. Upon successful registration, the user should return to the main dashboard to validate the real-time control functionality as shown in Figure 8.

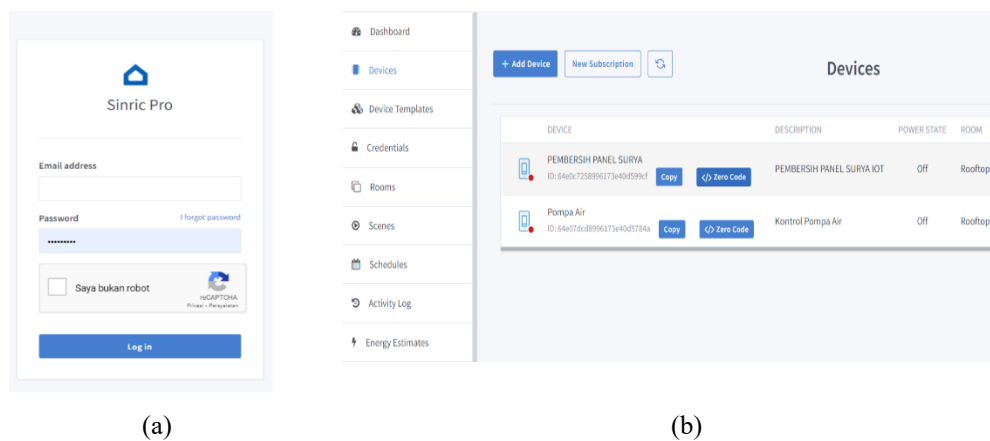


Figure 6. SinricPro login page (a), Website device page (b)

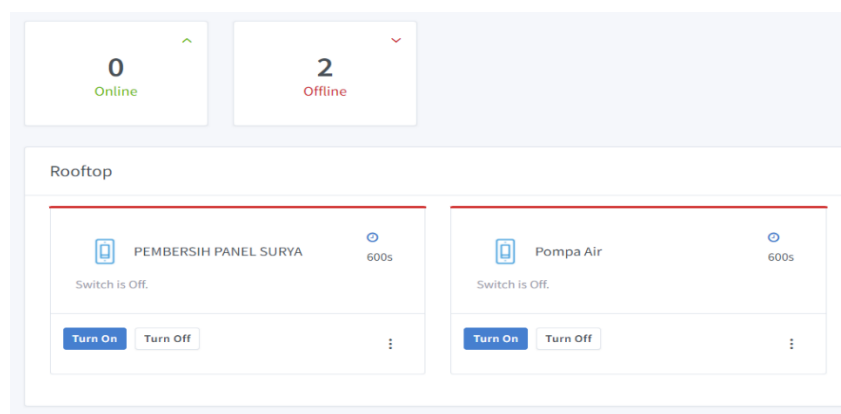
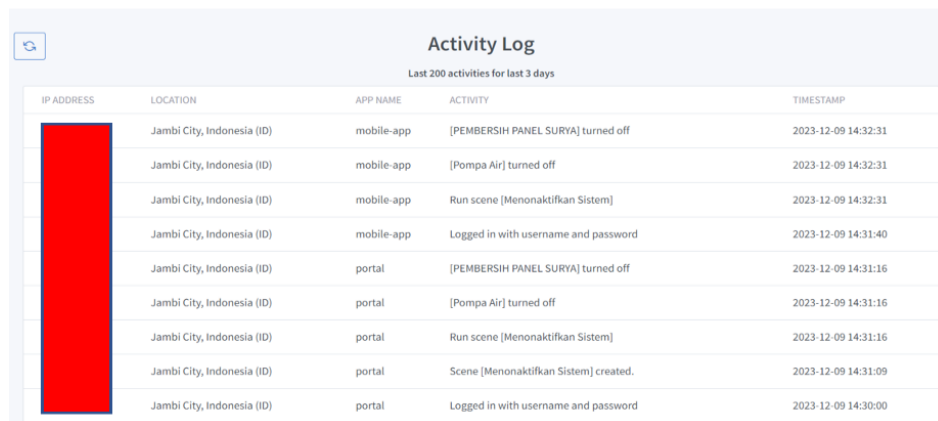


Figure 7. Website home page



IP ADDRESS	LOCATION	APP NAME	ACTIVITY	TIMESTAMP
[REDACTED]	Jambi City, Indonesia (ID)	mobile-app	[PEMBERSIH PANEL SURYA] turned off	2023-12-09 14:32:31
[REDACTED]	Jambi City, Indonesia (ID)	mobile-app	[Pompa Air] turned off	2023-12-09 14:32:31
[REDACTED]	Jambi City, Indonesia (ID)	mobile-app	Run scene [Menonaktifkan Sistem]	2023-12-09 14:32:31
[REDACTED]	Jambi City, Indonesia (ID)	mobile-app	Logged in with username and password	2023-12-09 14:31:40
[REDACTED]	Jambi City, Indonesia (ID)	portal	[PEMBERSIH PANEL SURYA] turned off	2023-12-09 14:31:16
[REDACTED]	Jambi City, Indonesia (ID)	portal	[Pompa Air] turned off	2023-12-09 14:31:16
[REDACTED]	Jambi City, Indonesia (ID)	portal	Run scene [Menonaktifkan Sistem]	2023-12-09 14:31:16
[REDACTED]	Jambi City, Indonesia (ID)	portal	Scene [Menonaktifkan Sistem] created.	2023-12-09 14:31:09
[REDACTED]	Jambi City, Indonesia (ID)	portal	Logged in with username and password	2023-12-09 14:30:00

Figure 8. Activity display of device testing activities

3 Result

3.1 Voice Commands Testing

This study phase focused on voice command validation to assess the sensitivity and accuracy of using Google Assistant to control the prototype. We applied a range of control vocabularies to rigorously test the system's responsiveness and recognition capability. Commands were delivered remotely via a mobile device utilizing the Google Voice platform to trigger the device's operational state. Data were then collected and validated to confirm the system's adherence to the predetermined control plan. Table 1 summarizes the specific voice commands and their corresponding test results.

Table 1. Results of voice commands testing

No.	Device	Voice Input	Voice Output	Status	Note
1	Wiper	<i>Ok Google nyalakan pembersih panel surya</i>	<i>Sip/Oke menyalakan pembersih panel surya</i>	ON	Compliant
2	Water Pump	<i>Ok Google nyalakan pompa air</i>	<i>Sip/Oke menyalakan pompa air</i>	ON	Compliant
3	Wiper	<i>Ok Google matikan pembersih panel surya</i>	<i>Sip/Oke mematikan pembersih panel surya</i>	OFF	Compliant
4	Water Pump	<i>Ok Google matikan pompa air</i>	<i>Sip/Oke mematikan pompa air</i>	OFF	Compliant

Table 1 presents the voice command validation results. The analysis confirms the system achieves successful actuation when the user issues the structured command: "Ok Google, nyalakan/matikan pembersih atau pompa air." Critically, Google Assistant first provides an auditory acknowledgment before relaying the command to the cloud-based control interface. The Status column in Table 1 verifies the system's functional compliance with each instruction. As all test cases showed successful operation (Compliant status), the prototype meets the anticipated performance objectives. This capability validates the system's potential to significantly reduce solar panel maintenance time by replacing manual procedures, concurrently mitigating occupational safety hazards.

3.2 Response Testing

This phase involved a responsiveness assessment designed to quantify the system's reaction time to control inputs. The testing protocol required the precise measurement of system latency, defined as the time interval between the initiation of a command and its successful execution by the device. Commands were systematically introduced through various modalities, including manual interface buttons (ON/OFF), automated scheduling, timed sequences (timer), and voice commands processed via the Google Voice platform. The elapsed time for each trial was meticulously recorded to analyze the system's performance across different input channels.

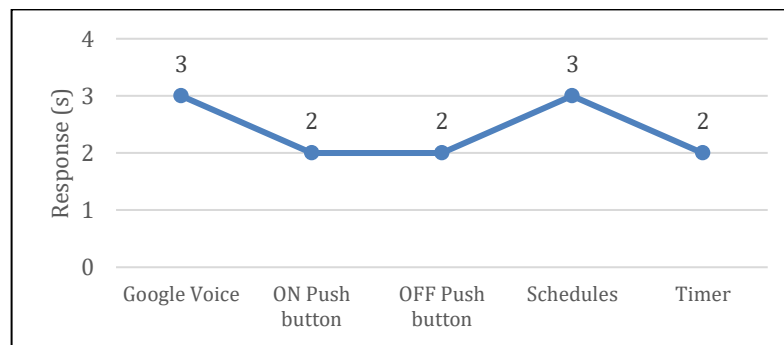


Figure 9. Response testing

Figure 9. Response testing presents the results of the system's responsiveness assessment. The data indicates that the control signals transmitted via direct physical interface (ON/OFF) and the timer mechanism elicited the shortest response times. Commands requiring cloud processing, specifically those originating from Google Voice and scheduled events, registered a marginally increased delay of approximately 3.0 seconds. Crucially, the average latency across all tested input methods was calculated to be 2.4 seconds. This rapid processing speed validates the control system's prompt and agile responsiveness, supporting the conclusion that the device can be activated efficiently, thus fulfilling the requirement for near-instantaneous operation.

3.3 Testing via Website and Application

The network-based control assessment was executed to determine the efficacy of command execution when inputs were generated solely from the web and application platforms. This testing was crucial for confirming the robust connection between the control server and the prototype hardware. A key feature of the system's design is its ability to transmit status notifications back to the user interface (website/application), allowing for remote monitoring of device activities and operational state.

Table 2. Website and application testing results

No	Device	Input Button	Website Notification	Status	Note
1	Wiper	ON	Device ON	ON	Compliant
2	Water Pump	ON	Device ON	ON	Compliant
3	Wiper	OFF	Device OFF	OFF	Compliant
4	Water Pump	OFF	Device OFF	OFF	Compliant

The data presented in Table 3 validates the efficacy of remote command execution through the digital control platforms. Successful manipulation of the device's operational state is achieved by clicking the ON/OFF buttons on the website or mobile application. A core function of the system is the immediate transmission of status notifications following any command, thereby providing the user with instantaneous confirmation of the device's condition. Additionally, the platform integrates an Activity Log (Figure 10a), which diligently records all user interactions and access points. This log is a critical component for system accountability, enabling administrators to monitor user activity and take appropriate measures regarding access management and security.

The system design features an Activity Log which users can immediately view essential attributes of system access, specifically: user authentication status, the geographical location of the accessing client, and the full temporal context (time, date, and calendar year) of the interaction. For enhanced security analysis, clicking the accompanying disclosure icon reveals extended data fields. These detailed fields include the connecting client's IP address and the device platform used for access (Figure 10b), providing necessary information for security protocol enforcement and incident tracking.

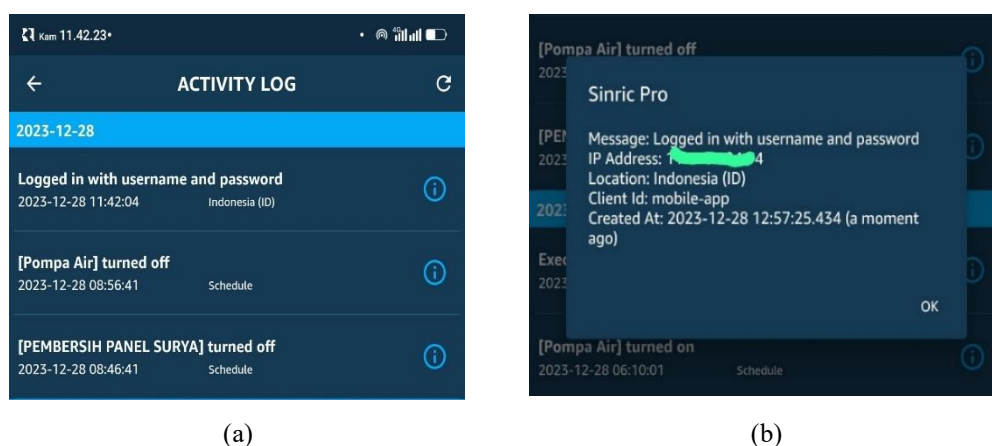


Figure 10. Interface of activity menu

3.4 Time-based Testing

This experimental phase involved a time-based performance assessment designed to compare the solar panel's electrical output before and after the automated cleaning cycle. Testing was conducted systematically in the morning, midday, and afternoon to account for diurnal variation in solar irradiance. The objective was to quantify the resulting increases in voltage, output current, and delivered power. Table 3 shows the voltage increase during experiment. Table 4 shows the power increase during experiments. Table 5 shows the current increase during experiments. To accurately quantify the improvement from the cleaning intervention, the percentage increase for each metric was calculated using Equation 1.

$$\text{Percentage increase} = \left(\frac{\text{Increment value} - \text{Initial value}}{\text{Initial value}} \right) \times 100\% \quad (1)$$

Table 3. Voltage increase

Day	Time	Voltage (Volt)		Deviation (Volt)	Increment (%)
		Before Cleaning	After Cleaning		
1	Morning	9.4	9.8	0.4	4.25
	Midday	20.1	20.8	0.7	3.48
	Afternoon	18.6	19.0	0.4	2.15
2	Morning	8.9	9.5	0.6	6.74
	Midday	20.2	20.9	0.7	3.46
	Afternoon	17.4	18.2	0.8	4.6
3	Morning	9.1	9.6	0.5	5.5
	Midday	19.8	20.4	0.6	3.03
	Afternoon	18.5	19.1	0.6	3.24

Table 4. Power increase

Day	Time	Voltage (Volt)		Deviation (Volt)	Increment (%)
		Before Cleaning	After Cleaning		
1	Morning	0.84	.98	0.14	16.67
	Midday	6.23	6.86	0.63	10.14
	Afternoon	3.72	3.99	0.27	7.26
2	Morning	0.71	.85	0.14	19.7
	Midday	6.26	6.68	0.42	6.7
	Afternoon	3.13	3.45	0.32	10.2
3	Morning	0.81	.86	0.05	6.1
	Midday	6.13	6.73	0.60	9.7
	Afternoon	3.7	3.82	0.12	3.24

Table 5. Current increase

Day	Time	Current (Ampere)		Deviation (Ampere)	Increment (%)
		<i>Before Cleaning</i>	<i>After Cleaning</i>		
1	Morning	0.09	0.10	0.01	11.11
	Midday	0.31	0.33	0.02	6.4
	Afternoon	0.20	0.21	0.01	5
2	Morning	0.08	0.09	0.01	12.5
	Midday	0.31	0.32	0.01	12.5
	Afternoon	0.18	0.19	0.01	5.5
3	Morning	0.09	0.09	0.00	0
	Midday	0.31	0.33	0.02	6.4
	Afternoon	0.20	0.20	0.00	0

4 Discussion

The operational testing confirms the high responsiveness of the developed prototype across all tested control modalities. The system demonstrated rapid and reliable command execution whether inputs were delivered via Google Voice, the dedicated web interface, or the mobile application. This achievement in minimal latency is critical for practical implementation, as immediate feedback is a core requirement for user satisfaction in Internet of Things (IoT) applications [19], [20].

All system interactions are meticulously logged within the Activity Log feature. This functionality serves as an invaluable audit trail, providing the user with real-time and historical data concerning all commands and the prototype's resulting actions. Furthermore, this monitoring capability is enhanced by recording essential metadata, including the accessing user's IP address, the specific client platform used, and the temporal and geographical context of the login event. This robust logging protocol significantly contributes to system security and accountability [21], [22]. Beyond the Activity Log, the system ensures user awareness through real-time push notifications, which instantly communicate the prototype's current operational status and ongoing activities.

The cleaning intervention demonstrated a measurable increase in electrical output following the restoration of the panel surface. Post-cleaning, the photovoltaic panel achieved an output voltage of 20.8 V, a power output of 6.86 W, and a current output of 0.33 A. These recovered values validate the system's effectiveness in mitigating power degradation caused by soiling, a finding consistent with prior research emphasizing the benefits of automated cleaning in solar panel efficiency [23], [24].

The energy consumption required for the cleaning cycle is highly efficient. The mechanical actuation consumes an equivalent power of 0.75 W for the full rotation to the left and another 0.75 W for the return sweep. Consequently, a complete cleaning cycle (two full rotations) necessitates a total energy expenditure of only 1.5 W.

The total duration of a single cleaning cycle is also optimized. One rotation to the far end takes 15 seconds, while the return trip requires 17 seconds. Therefore, a full cleaning cycle is completed in a total duration of 32 seconds. The low energy expenditure and rapid cleaning time underscore the prototype's potential for long-term operational sustainability and cost-effectiveness compared to manual labor alternatives.

This study acknowledges several limitations inherent to the current prototype design, which provide clear directions for future work. The prototype currently lacks a feature for real-time monitoring of battery capacity within the web and application interfaces, which is crucial for operational planning. Furthermore, the water delivery system relies on the wiper mechanism for distribution; future iterations should aim to implement a system that can uniformly moisten the entire panel surface independently of the sweeping motion. Finally, the prototype is presently powered by a dedicated 9V battery. For true self-sufficiency and scalability, the system's power supply should be developed to draw electrical current directly from the solar panel array, eliminating the need for an internal battery as the primary power source.

5 Conclusion

The developed Internet of Things (IoT)-enabled solar panel cleaning prototype successfully validated its core functional and operational objectives. The system demonstrated high responsiveness and reliability across all control modalities, including Google Voice, web, and mobile application inputs, achieving a commendable mean response time of 2.4 seconds. System integrity and user accountability are maintained through a robust Activity Log and real-time status notifications, enhancing security by tracking essential access metadata.

Critically, the cleaning intervention proved effective, leading to a measurable recovery in power output, exemplified by post-cleaning values of 20.8 V and 6.86 W. The mechanical system is highly optimized for sustainability, consuming a minimal total power of only 1.5 W for a complete cleaning cycle, which is executed rapidly in 32 seconds.

In summary, the prototype is functionally compliant with the design specifications and represents a viable, efficient, and low-energy solution that can substantially streamline solar panel maintenance while mitigating the occupational hazards associated with manual cleaning procedures. This success validates the application of IoT technology as an effective paradigm for automated PV system upkeep.

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