

2 **A Dual Axis IoT-Based Off-Grid Solar Tracking** 3
System with Wheatstone Bridge for Efficient
4 **Energy Harvesting and Management**

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ABSTRACT

Addressing the increasing need for sustainable energy solutions, this study presents an advanced dual-axis solar tracking system. By integrating IoT-based intelligent power management and automated panel cleaning, we aim to optimize the efficiency of solar photovoltaic (PV) systems. Our design significantly outperforms traditional fixed PV setups, achieving an average voltage improvement of about 18.59% throughout the day. Real-time data monitoring showcases the system's adaptability, with Solar Voltage (SV) and Solar Current (SC) standard deviations recorded at 1.059 and 0.058, respectively. This system not only captures sunlight more efficiently but also ensures self-maintenance, reducing manual intervention. The integration of IoT capabilities provides real-time feedback and adaptability. In the backdrop of global energy challenges, especially post-COVID-19, our innovative approach to solar energy promises reduced environmental impact and utility costs.

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23 *Keywords: Dual Axis, Solar Tracking, Panel Cleaning, Smart Power Management.*

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26 **1. INTRODUCTION**

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28 *The rising carbon footprint and global warming result from the increased use of fossil fuels to*
29 *generate power. In light of this, renewable energy has emerged as the most viable long-term*
30 *strategy for reducing the negative impacts of fossil fuels [1]. Solar energy has attracted much*
31 *interest among renewable energy sources because of its inexpensive production and*
32 *installation costs, ability to function off-grid, and nearly nonexistent maintenance expenses [2].*
33 *The maximal output of a solar photovoltaic (PV) system is contingent upon the efficient*
34 *utilization of solar energy. An intelligent solar system is required to ensure optimal solar*
35 *electricity utilization based. On-demand and to maintain system efficiency by preventing*

Comment [14]: *This paragraph should be rephrase in a logical flow of ideas.*

36 excessive heat and grime accumulation on the PV [3]. In recent years, there has been a
37 significant increase in research and development endeavours focused on enhancing solar
38 tracking systems by utilizing Internet of Things (IoT) technologies. These systems are
39 engineered to improve the productivity and efficiency of solar panels by adaptively modifying
40 their orientation in accordance with current environmental circumstances. A solar tracking
41 system equipped with IoT technology and intelligent features utilizes sensors, actuators, and
42 IoT capabilities to improve the energy efficiency of solar power systems [4]. Extensive
43 testing has shown that this system has achieved a considerable improvement of up to 28.3%
44 in energy production compared to traditional fixed-mount systems. This highlights its
45 potential to improve the use of renewable energy [4] significantly. In addition, methods that
46 utilize analog controllers, such as those that combine Wheatstone bridge circuit functions
47 with lightdependent resistors (LDRs), provide immediate feedback on the intensity of
48 sunlight. This allows for accurate adjustments to the orientation of photovoltaic (PV) panels
49 in order to capture sunlight optimally [6]. These closed-loop control systems optimize energy
50 generation and promote the effective exploitation of solar resources [5]. In addition, the
51 incorporation of maximum power point tracking (MPPT) devices with Internet of Things (IoT)
52 technology enables immediate monitoring and control of solar power generation and battery
53 charging, hence improving energy efficiency and sustainability [6]. Another significant
54 advancement is the emergence of solar tracking systems powered by IoT and machine
55 learning algorithms. These systems dynamically modify the angles of solar panels by
56 analyzing data on the sun's position and cloud cover [7]. Moreover, these systems include
57 the potential to be remotely monitored and controlled, hence improving their flexibility and
58 ease of use [7]. Furthermore, the combination of IoT and Raspberry Pi technology has
59 resulted in advanced solar tracking systems that are cost-effective and adaptable, making
60 them appropriate for many uses, such as home and small-scale business environments [8].
61 Through the automation of solar panel movement and the optimization of energy capture
62 throughout the day, these systems have shown substantial enhancements in energy output
63 compared to stationary solar arrays [8]. Ultimately, dual-axis solar tracking systems,
64 supported by the Internet of Things (IoT), have emerged as viable alternatives for optimizing
65 solar energy gathering. By utilizing remote monitoring and feedback control methods, these
66 systems maximize the positioning of solar panels in relation to sunlight, resulting in
67 significant improvements in energy collection efficiency compared to fixed-tilt panels [9]. By
68 using power management strategies, the amount of energy consumed may be further
69 reduced. This highlights the capabilities of these systems to improve sustainability and
70 efficiency in the exploitation of solar energy [9]. These achievements highlight a positive
71 trend towards strengthening the use of renewable energy and promoting a sustainable
72 energy environment. This study proposes an innovative PV solar system based on the
73 Internet of Things to maximize residential use of solar energy while decreasing reliance on
74 conventional grid power and utility costs. The primary outcomes of this project are the dual-
75 axis solar tracker, the auto-cleaning mechanism for the panels, and the incorporation of IoT
76 devices for condition monitoring and power optimization. Extreme heat, dust buildup on
77 panels, and discussion shading all lower solar PV systems' efficiency. That's why it's
78 essential to create an innovative solar system that can make the most of the sun's rays,
79 keep tabs on itself, and get repairs done quickly and cheaply, all while connecting to the
80 Internet of Things (IoT) for remote monitoring and control.

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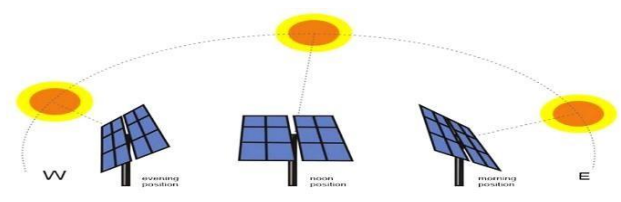


Fig. 1. Dual-axis solar tracking system

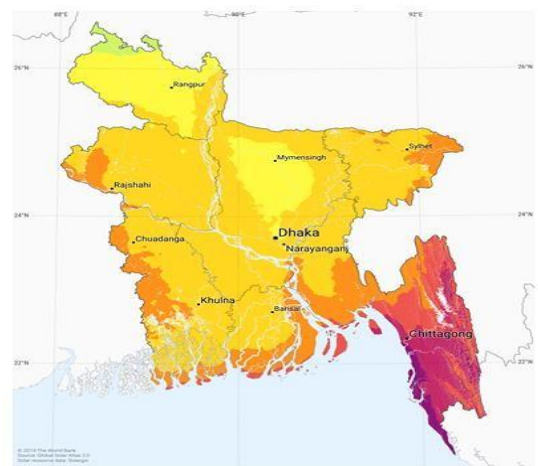


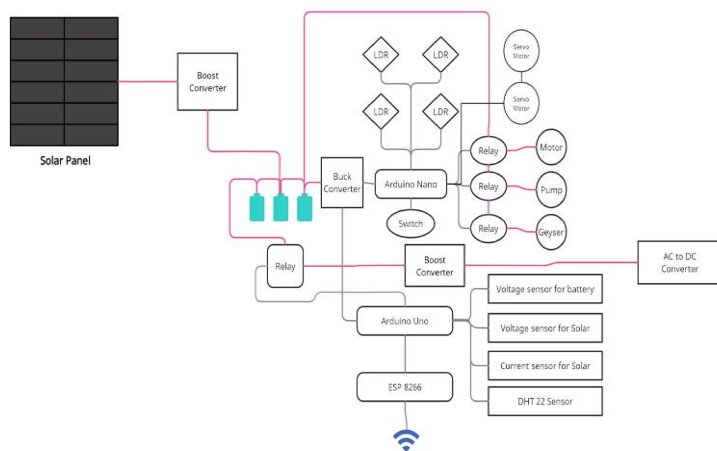
Fig. 2. Solar irradiance area of Bangladesh and Project test location.

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87 We propose a system with automatic panel cleaning and solar tracking to maximize energy
88 harvesting potential. We also use Internet of Things (IoT) gadgets to track and report data
89 like solar energy output, battery life, and ambient temperature from a central location. The
90 electricity demand is expected to continue rising globally, particularly in the post-COVID era,
91 as reported by the International Energy Agency (IEA) [10].

92 **2. METHODOLOGY**
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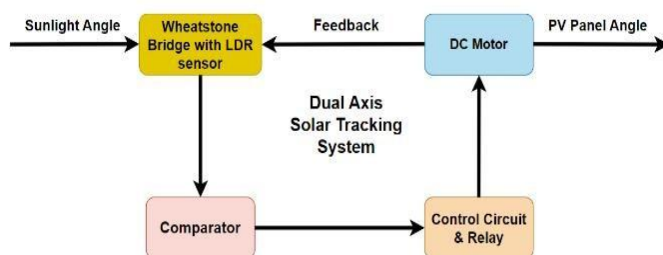


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Fig. 3. System Structure Block Diagram

97 *The block diagram of the system structure (Fig. 3) depicts the system's overall operation.*
 98 *The system includes a solar panel that generates the essential energy for the system to*
 99 *function. A boost converter improves the power supply's efficiency by converting a reduced*
 100 *voltage to a higher voltage. A 14.8-volt Lithium-ion battery cell is incorporated to store and*
 101 *provide energy to the system. Two boost converters are implemented in the design, one to*
 102 *increase the voltage of the solar panel to 16.8 volts and the other to increase the voltage of*
 103 *the 12-volt AC to DC converter to 16.8 volts, as the battery pack reaches 16.8 volts when*
 104 *ultimately charged. The Wheatstone Bridge was first used to measure shallow resistance*
 105 *values. It is more precise than many other techniques and operates by dividing the voltage.*
 106 *One of the most essential and well-known applications of the Wheatstone bridge circuit is*
 107 *measuring the variations of the sensor resistance [11].*

108 *The Dual Axis Solar Tracking control system is a closed-loop system that incorporates the*
 109 *utilization of a Wheatstone bridge circuit and light-dependent resistors (LDRs). A compact*
 110 *and purpose-built Dual Axis Solar Tracking control system was developed and constructed*
 111 *to authenticate the proposed system. The effectiveness and efficiency of the system were*
 112 *then confirmed. The reference input signal in the closed-loop dual-axis solar system is*
 113 *determined by the intensity of sunlight, as depicted in Fig 4. To facilitate solar tracking, it is*
 114 *necessary to employ optical sensors to accurately identify the position of the sun. The*
 115 *tracking system being proposed utilizes optical sensors to adjust the photovoltaic (PV) panel*
 116 *in accordance with the sun's angle.*



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Fig. 4. Dual Axis Solar System Block Diagram

119 As light intensity increases, LDR sensors' electrical resistance decreases. A voltage
 120 differential emerges from an LDR sensor-generated voltage imbalance in the Wheatstone
 121 bridge branches. Figure 2 shows the difference between solar radiation angle and PV panel
 122 position. The Wheatstone bridge output voltage is then boosted by the operational amplifiers
 123 (op-amps). Control circuits trigger the relay using operational amplifier output voltage. The
 124 relay starts engine rotation in the tracking system to move it in the right direction. Under ST
 125 control, the PV panel will rotate on its axis. This automatic mechanism positions the PV
 126 panel at the proper angle to the sun [12]. This process continues until the voltage disparity in
 127 the bridge branches decreases below a predetermined threshold value.

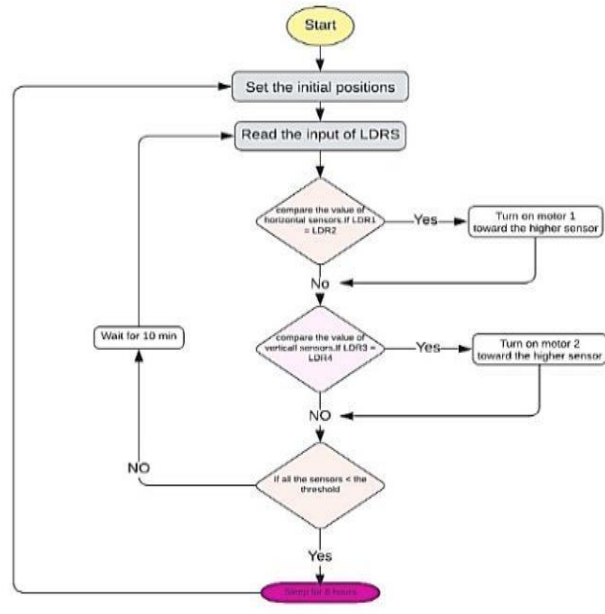
128 A Buck converter is used to supply 5 volts to the microcontroller and servo actuator. Two
 129 boost converters are required because the solar panel's voltage output is unstable and
 130 dependent on several variables, such as the intensity of sunlight, temperature, and shading
 131 effects. Three microcontrollers, Arduino NANO, Arduino Uno, and ESP 8266 are
 132 incorporated into the system's design. Arduino NANO controls dual-axis solar tracking
 133 systems, cleans solar panels, and operates geyser systems. The LDR sensor determines
 134 the movement of the servo motor, and the cleaning motor and pump are activated at
 135 predetermined intervals. In addition, the geyser system can be controlled via a valve.
 136 Arduino Uno is outfitted with two voltage sensors, a current sensor, and a DHT 22 sensor
 137 (consisting of a humidity sensor and a thermistor to measure air and generate digital data
 138 directly). The detected data is then transmitted via serial communication to ESP 8266. The
 139 data is sent to the web server by ESP 8266.

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140 **2.1 Dual Axis Solar Panel Movement Flowchart**

141 Fig. 5 represents the Dual Axis Solar Panel Movement flowchart depicts the sequence of
 142 actions to be carried out by the command. The program begins with the power to commence
 143 and then directs the solar panel to its initial position. It accumulates and processes all the
 144 LDR sensor inputs. The program contrasts the values of the horizontal sensor data, namely
 145 whether LDR1 and LDR2 are equivalent. If the result is positive, Motor1 will be commanded
 146 to move towards the sensor above it. However, if the impact is negative, the program
 147 immediately compares the values of vertical LDR sensors. It determines whether LDR3 is

148 equal to LDR4. If the result is positive, it instructs Motor2 to move towards the higher-up
149 sensor.
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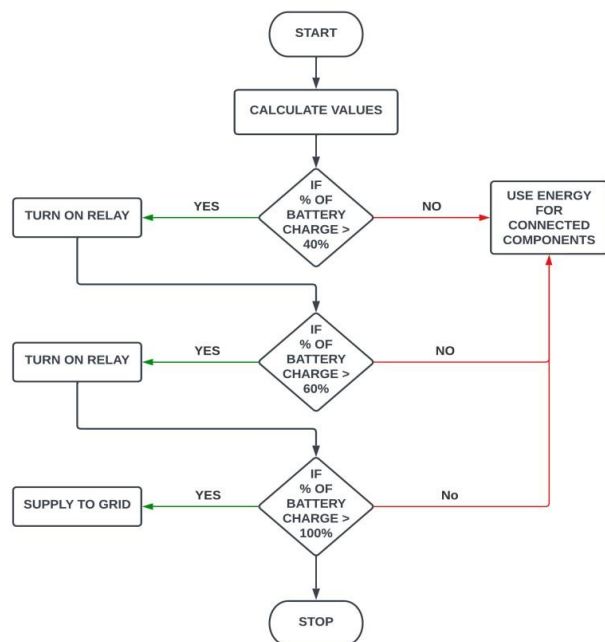
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Fig. 5. Dual-axis solar panel movement flowchart

154 If the result is negative, the program then determines whether all sensor values are below
155 the threshold value. If the result is negative, the program delays ten minutes before
156 rereading the LDR sensor values. If the result is positive, the program sleeps for six hours
157 and restarts the procedure by repositioning the solar panel.

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159 **2.2 Power System Flow Diagram**



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162 **Fig. 6. Power management system flowchart**

Comment [17]: Sources of these diagram/figure should cited

163 Fig. 6 depicts a comprehensive overview of the sequential steps the power management
164 system follows in response to user commands. The flowchart begins with the "start"
165 command and continues with the battery's charge percentage calculation. If it is determined
166 that the battery charge is 40%, the system will command the relay to power on. An alarm
167 will sound if the battery charge declines below 40%. The system will also control the relay to pull
168 on when the battery charge reaches 60%. When the battery reaches its maximum capacity,
169 the system will command the excess generating current to be supplied to the grid.

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171 **3. DESIGN AND SIMULATION**

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173 SolidWorks, a popular CAD software, was used to construct an elaborate 3D model of the
174 project in Fig 7. The 3D model correctly depicts the project concept and demonstrates the
175 anticipated conclusion. System-critical solar panels are on top of the model. LDR
176 (lightdependent resistor) sensors on the top and a gear motor on the left ensure precise
177 solar panel cleaner control. Two strategically placed servo motors for horizontal and vertical
178 axis movements enable dual-axial rotation for better tracking. For precise and smooth motor
179 positioning, a well-designed frame is needed. A hardware component box holds vital system

180 components and is delicately attached to the frame. The model's bottom battery ensures
181 power supply, maximizing space utilization and system performance.
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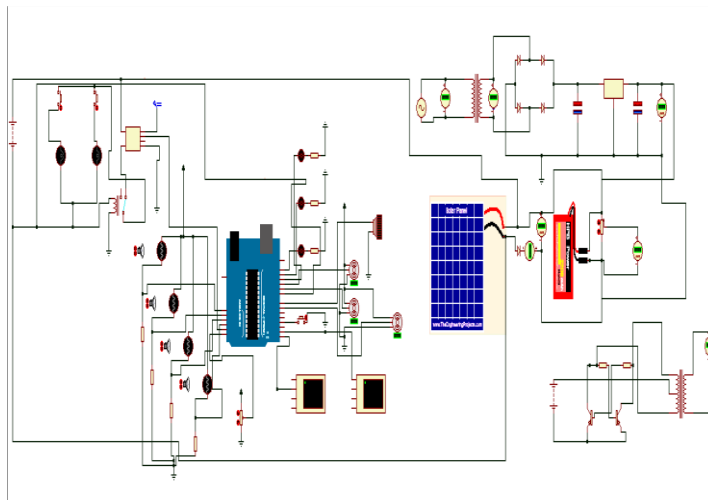
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Fig. 7. Prototype 3D model of the project.

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188 **3.1 Simulation of Robotic System and Operation**

189 Fig. 8. displays the Simulation models assessing the IoT-based intelligent photovoltaic solar
190 power system's performance before construction. It lets you test multiple design
191 configurations and operating parameters and predict system performance. Simulation
192 models can estimate a solar power system's energy output, battery charge, and efficiency in
193 varied weather conditions.

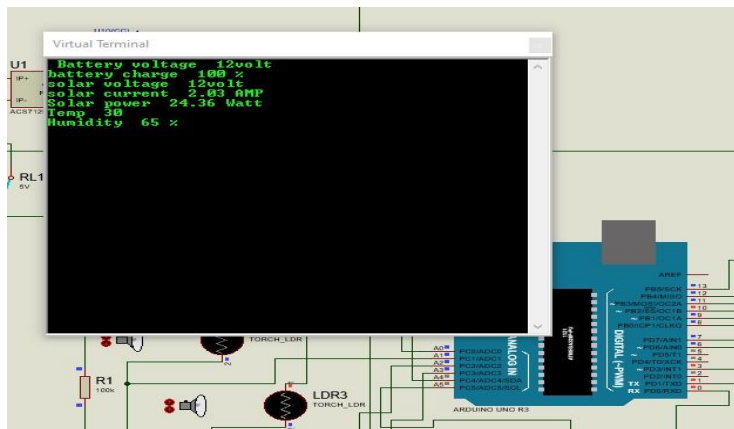


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Fig. 8. Micro-controller-based Power controller system designed in Proteus.

197 The simulation of the robotic system and its operations was carried out with the help of the
198 Proteus program. Fig. 9 shows that **An** Arduino Uno R3 microcontroller served as the
199 simulation's primary processing unit, and its use was facilitated by incorporating this
200 component into its design. Within the simulation, there were a total of four LDR sensors
201 used. In addition, the simulation was equipped with three servo motors, which stood in for
202 the cleaning brush motor, the horizontal axis motor, and the vertical axis motor, respectively.
203 Additionally, to raise the voltage of both the solar panels and the 12-volt AC to DC converter,
204 the system was equipped with two boost converters. The objective of these converters was
205 to enhance the voltage. In addition, a buck converter was developed to supply energy to the
206 microcontroller and the servo motor at a voltage of 5 volts. In the final step of the simulation,
207 an energy storage device comprised of a solar panel and a battery was used.

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Fig. 9. Simulation result of micro-controller-based power controller system

211 **3. IMPLEMENTATION & RESULT**

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Fig. 10 depicts the final prototype of a project that includes a dual-axis solar tracking system, a panel cleaning system, and a power management system. Previously, a 3D model of the project was presented, and now its completion has been accomplished. The final product is a solar panel that converts sunlight into electricity. On the upper portion of the meeting, there are LDR sensors, and on the right side, there is a cleaner gear motor to move the cleaning brush across the solar panel. A horizontal servo motor is located beneath the board and is responsible for horizontal panel movement. The buck converter and vertical servo motor, which move the panel along the vertical axis, are located beneath this. This results in a dual axis tracking system for the project, enabling the solar panel to be moved along both the horizontal and vertical dimensions.



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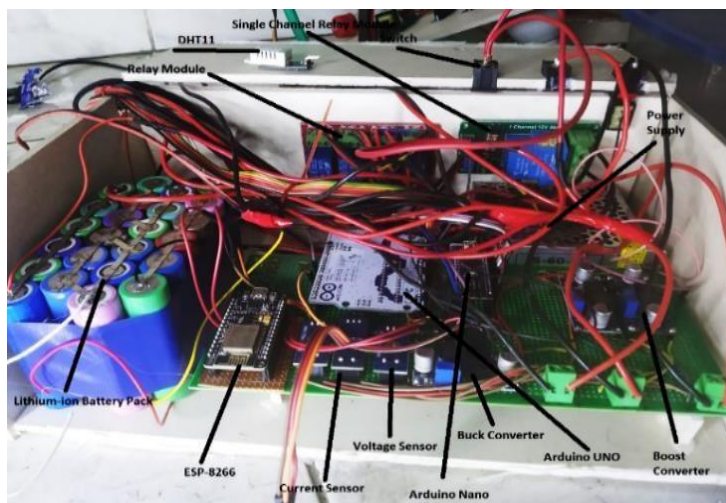
Fig. 10. Implemented dual-axis solar tracking, panel cleaning, and power management system project.

228 Fig. 11 depicts a top view of the project, displaying the solar panel, LDR sensors, cleaner,
229 and cleaner gear motor. The solar panel and LDR sensors work together as a tracking
230 system component, whereas the cleaner and cleaner motor facilitate the solar panel
231 cleaning system.



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234 **Fig. 11. Top view of solar sun tracking and cleaning system.**

235 Fig. 12 depicts the sun monitoring and dual-axis movement systems incorporated into the
236 project. The primary function of the dual-axis movement system is to allow the solar panel
237 to move horizontally and vertically. This is accomplished by employing a horizontal servo motor
238 to facilitate movement in the horizontal plane and a vertical servo motor to boost the solar
239 panel about its vertical axis. In addition, a buck converter is integrated into the system to
240 provide 5 volts of stable power to the microcontroller and servo actuator.
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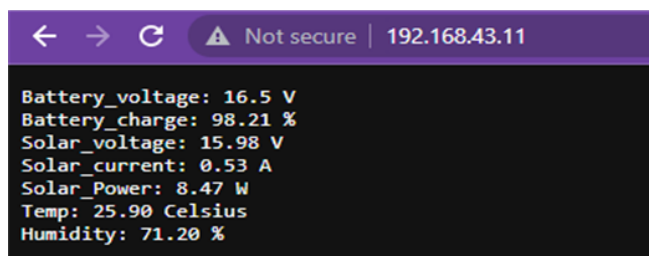
244 **Fig. 12. Inside of hardware primary device**

245 Fig. 13 depicts the project's primary terminal unit for power and control. This image
 246 represents all of the project's constituent parts. The Arduino Uno, Arduino Nano, and ESP
 247 8266 are readily identifiable as the project's primary processing devices. Additionally, the
 248 image displays the Boost and Buck converters. The lithium-ion battery cell is positioned on
 249 the image's left side. In addition, the painting depicts one current sensor and one voltage
 250 sensor used for measuring purposes. The image's reverse side displays the motor control
 251 and singlechannel relay modules. In addition, DHT11 and the switch are located adjacent to
 252 these modules.

253 The simulation result is seen in this photo, which depicts the virtual terminal. It displays the
 254 voltage of the battery, as well as the battery's percentage of charge, and the voltage,
 255 current, and power of the solar panel. The system draws power from the grid if the battery
 256 charge is lower than 40 percent, equivalent to 4.2 volts. Let's say that the battery has 4 volts.
 257 The battery pack operates at 16.8 volts. The calculation is:

258
$$= ((4*100)/16.8) \% = 23.81\%$$

259 In this situation, this system takes power from the grid.
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 263 **Fig. 14. Hardware result of the Project in a Web-based interface.**

264 Fig. 14 displays the outcome of the implemented gadget. <https://192.168.43.11> is the
 265 Internet Protocol address of the data display website.

266 **Table 1. The Percentage Improvement in Voltage for The Dual Axis Setup Over the**
 267 **Fixed PV Setup**
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Time (Hour)	Fixed PV Setup (V)	Dual Axis Setup (V)	Improvement Voltage (%)
06.00 AM	8.89	10.14	14.06
07.00 AM	10.25	12.57	22.63
08.00 AM	12.31	14.33	16.41
09.00 AM	13.36	14.69	9.96
10.00 AM	13.89	15.11	8.78
11.00 AM	14.02	15.34	9.42
12.00 PM	15.13	15.98	5.62
01.00 PM	14.46	15.66	8.30
02.00 PM	13.67	15.25	11.56
03.00 PM	12.49	14.82	18.65
04.00 PM	10.92	14.16	29.67

05.00 PM	9.14	13.63	49.12
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270 *In Table 1, the average percentage improvement over the day is approximately 18.59%. This*
 271 *means, on average, the Dual Axis Setup provides an 18.59% improvement in voltage over*
 272 *the Fixed PV Setup throughout the day. This result shows that the Dual Axis Setup is*
 273 *significantly more efficient than the fixed PV Setup, as it consistently produces higher*
 274 *voltage outputs across all times of the day.*

275

276 *Table 2, shows the hardware findings from a monitoring day from 6:00 AM to 6:00 PM.*
 277 *Battery voltage, battery charge, solar voltage, solar current, solar power, temperature, and*
 278 *humidity are all included in the findings. Where, Temperature, humidity, light intensity, and*
 279 *electricity output from solar panels are all displayed. Short forms used in the table are*
 280 *Battery Voltage = BV, Battery charge = BC, Solar Voltage = SV, Solar Current = SC, Solar*
 281 *power = SP, Temperature = Temp, Humidity = Hum.*

282

283 **Table 2. Implemented Hardware Result**

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Time	BV	BC	SV	SC	SP	Temp	Hum
6 AM	15.3	90.54 %	10.14	0.13	0.91	23.2	70.88
7 AM	15.4	91.28 %	12.57	0.14	0.95	23.9	70.96
8 AM	15.5	92.26 %	14.33	0.14	0.98	24.8	71.07
9 AM	15.6	92.85 %	14.69	0.14	1.2	25.0	71.02
10 AM	15.7	93.45 %	15.11	0.16	1.45	25.0	71.30
11 AM	15.9	94.65 %	15.34	0.19	1.99	27.20	72.05
12 PM	16.0	95.23 %	15.87	0.19	2.08	27.46	72.43
1 PM	16.2	96.4 %	15.66	0.21	2.74	27.40	72.44
2 PM	16.5	98.21 %	15.25	0.35	6.25	28.05	71.03
3 PM	16.8	100 %	14.82	0.25	4.12	26.01	71.67
4 PM	16.8	100 %	14.16	0.27	4.18	24.47	70.04
5 PM	16.8	100 %	13.63	0.30	5.07	23.41	70.38
6 PM	16.8	100 %	11.91	0.21	3.42	23.19	70.18

285

286 *The solar voltage (SV) rises from 6 AM, peaks around midday, and then diminishes, aligning*
 287 *with anticipated solar intensity patterns. The consistent SV curve indicates the system's*
 288 *efficient adaptability to sunlight variations. Similarly, the solar current (SC) follows this trend*
 289 *but has a distinct surge at 2 PM, possibly due to unique environmental circumstances. Solar*
 290 *power (SP), being the result of voltage and current, mirrors these trends, with a marked*
 291 *spike at 2 PM, signaling a notable boost in energy production. In essence, the steady SV*
 292 *and SC trends highlight the system's effective response to daily solar changes, proving the*
 293 *Dual Axis Setup's capability in optimal solar tracking and energy harnessing. The standard*
 294 *deviations for rate changes in Solar Voltage (SV) and Solar Current (SC) are 1.059 and*
 295 *0.058, respectively. The SC low value indicates a smoother and more consistent response*
 296 *to daily solar variations. Both values suggest the system effectively adapts to changing solar*
 297 *conditions [13].*

298 **4. CONCLUSION**

299

300 *In this study, we successfully engineered a dual-axis solar tracking system, realizing an*
301 *average voltage improvement of approximately 18.59% over traditional fixed PV setups. Our*
302 *system's incorporation of an automated cleaning mechanism and IoT capabilities ensured*
303 *real-time monitoring and adaptability, as evidenced by the Solar Voltage (SV) and Solar*
304 *Current (SC) standard deviations of 1.059 and 0.058, respectively. Future directions include*
305 *integrating AI for optimal panel orientations, fortifying IoT security, exploring advanced*
306 *battery storage solutions, enhancing system scalability, and merging with other renewable*
307 *energy sources. This endeavor represents a significant leap in sustainable solar energy*
308 *solutions, promising broader applications in the future.*

309

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Comment [11]: Proper reference list should be done