

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.

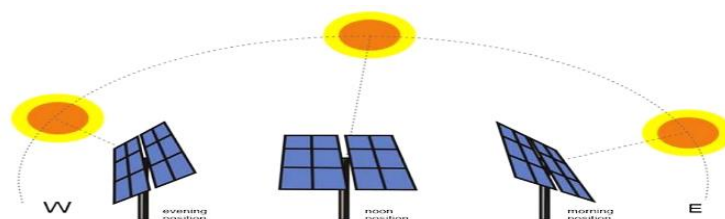
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Keywords: Dual Axis, Solar Tracking, Panel Cleaning, Smart Power Management.

1. INTRODUCTION

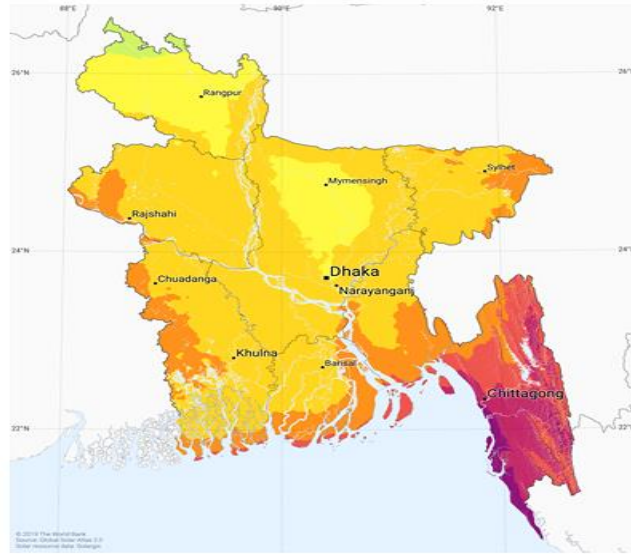
The rising carbon footprint and global warming result from the increased use of fossil fuels to generate power. In light of this, renewable energy has emerged as the most viable long-term strategy for reducing the negative impacts of fossil fuels [1]. Solar energy has attracted much interest among renewable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

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



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Fig. 1. Dual-axis solar tracking system



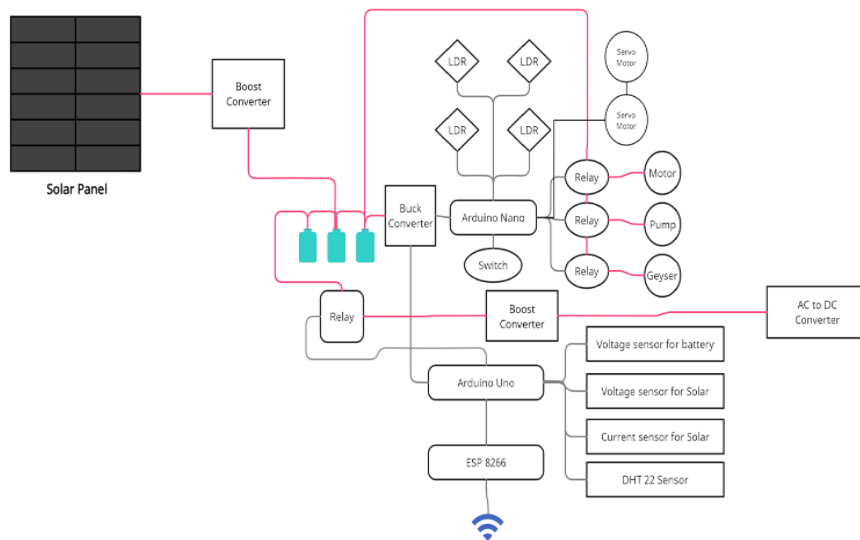
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Fig. 2. Solar irradiance area of Bangladesh and Project test location.

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

91 **2. METHODOLOGY**

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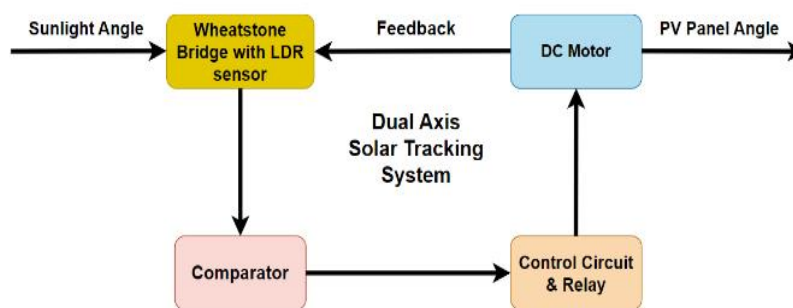


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Fig. 3. System Structure Block Diagram

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

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



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Fig. 4. Dual Axis Solar System Block Diagram

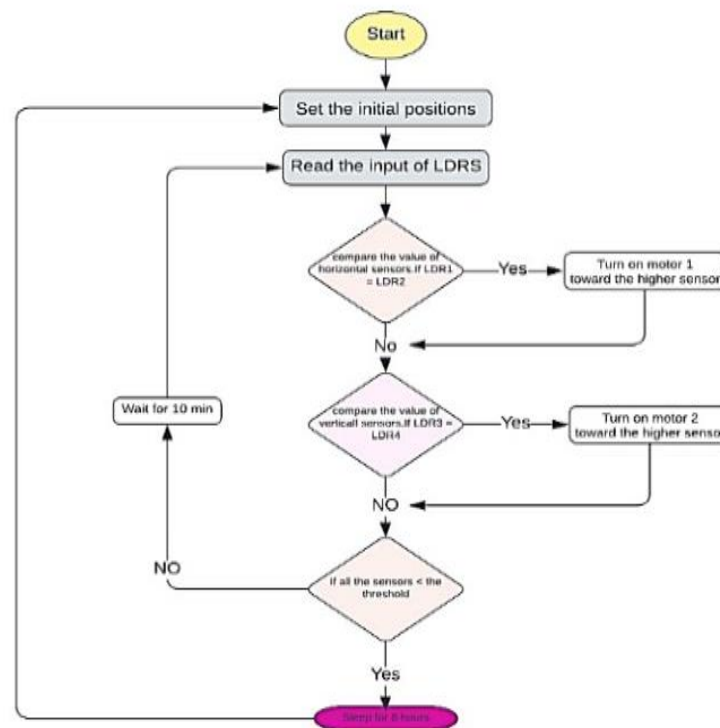
118 As light intensity increases, LDR sensors' electrical resistance decreases. A voltage
 119 differential emerges from an LDR sensor-generated voltage imbalance in the Wheatstone
 120 bridge branches. Figure 2 shows the difference between solar radiation angle and PV panel
 121 position. The Wheatstone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

127 A Buck converter is used to supply 5 volts to the microcontroller and servo actuator. Two boost
 128 converters are required because the solar panel's voltage output is unstable and dependent
 129 on several variables, such as the intensity of sunlight, temperature, and shading effects. Three
 130 microcontrollers, Arduino NANO, Arduino Uno, and ESP 8266 are incorporated into the

131 system's design. Arduino NANO controls dual-axis solar tracking systems, cleans solar
 132 panels, and operates geyser systems. The LDR sensor determines the movement of the servo
 133 motor, and the cleaning motor and pump are activated at predetermined intervals. In addition,
 134 the geyser system can be controlled via a valve. Arduino Uno is outfitted with two voltage
 135 sensors, a current sensor, and a DHT 22 sensor (consisting of a humidity sensor and a
 136 thermistor to measure air and generate digital data directly). The detected data is then
 137 transmitted via serial communication to ESP 8266. The data is sent to the web server by ESP
 138 8266.

139 2.1 Dual Axis Solar Panel Movement Flowchart

140 Fig. 5 represents the Dual Axis Solar Panel Movement flowchart depicts the sequence of
 141 actions to be carried out by the command. The program begins with the power to commence
 142 and then directs the solar panel to its initial position. It accumulates and processes all the LDR
 143 sensor inputs. The program contrasts the values of the horizontal sensor data, namely whether
 144 LDR1 and LDR2 are equivalent. If the result is positive, Motor1 will be commanded to move
 145 towards the sensor above it. However, if the impact is negative, the program immediately
 146 compares the values of vertical LDR sensors. It determines whether LDR3 is equal to LDR4.
 147 If the result is positive, it instructs Motor2 to move towards the higher-up sensor.
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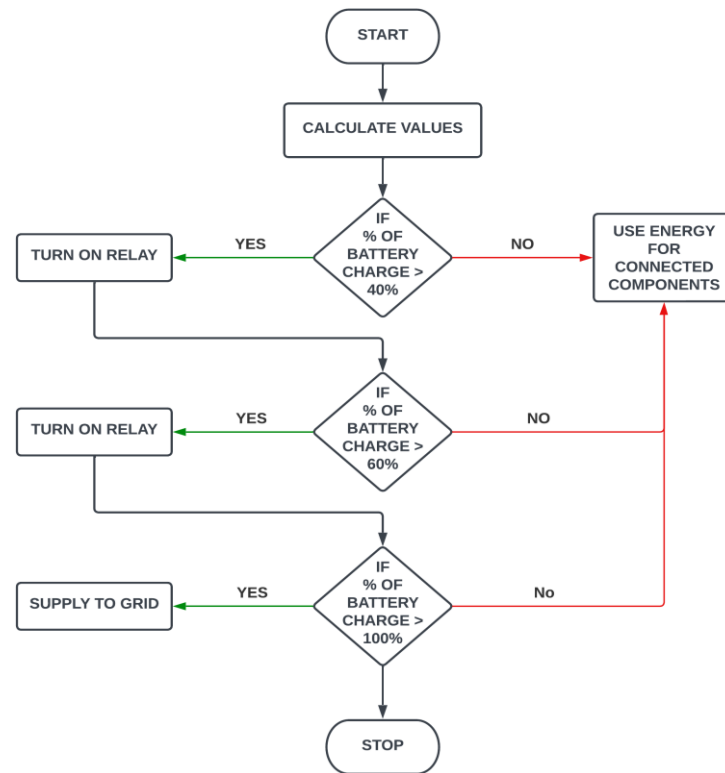


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Fig. 5. Dual-axis solar panel movement flowchart

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

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157 **2.2 Power System Flow Diagram**

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Fig. 6. Power management system flowchart

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

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3. DESIGN AND SIMULATION

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

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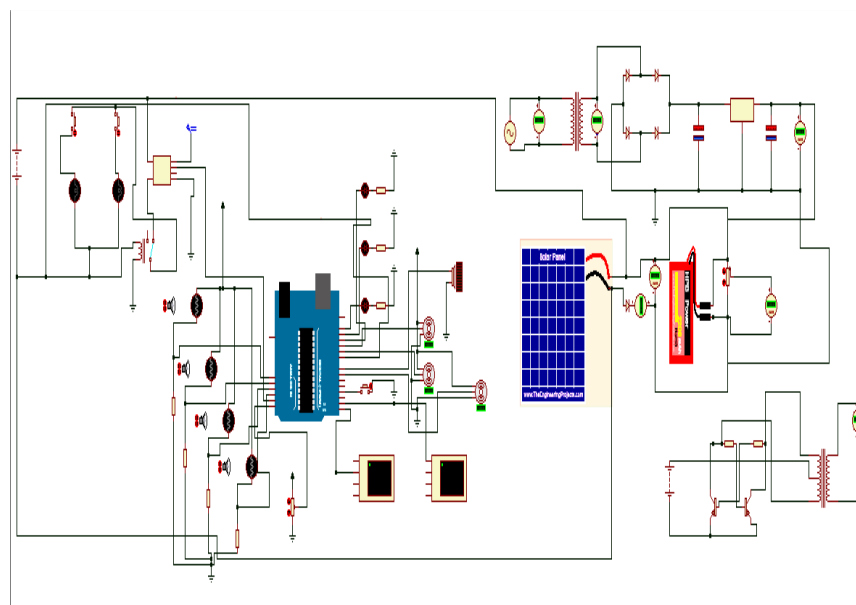


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Fig. 7. Prototype 3D model of the project.

185 **3.1 Simulation of Robotic System and Operation**

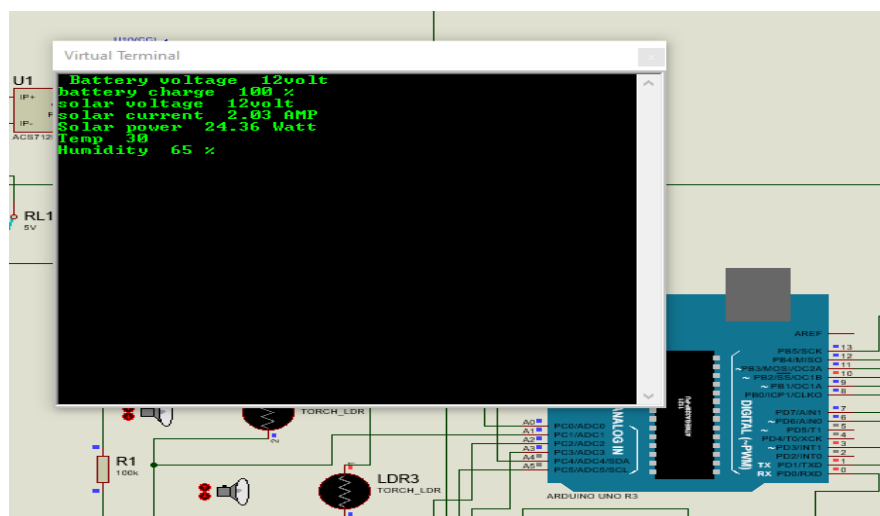
186 Fig. 8. displays the Simulation models assessing the IoT-based intelligent photovoltaic solar
 187 power system's performance before construction. It lets you test multiple design configurations
 188 and operating parameters and predict system performance. Simulation models can estimate
 189 a solar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



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

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

208 3. IMPLEMENTATION & RESULT

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

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



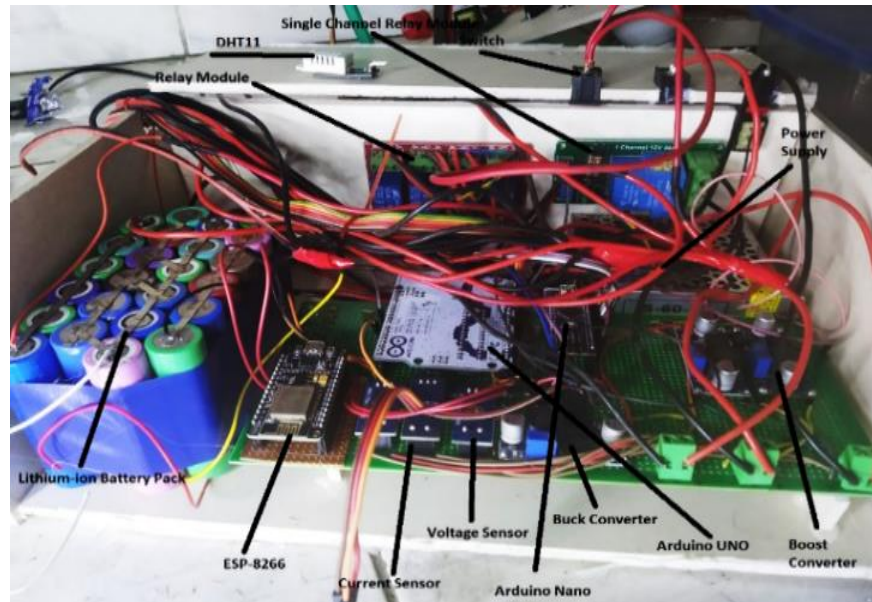
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Fig. 11. Top view of solar sun tracking and cleaning system.

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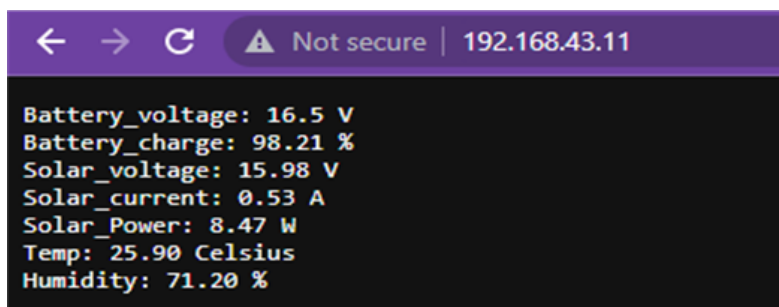
Fig. 12. Inside of hardware primary device

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

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

254
$$= ((4*100)/16.8) \% = 23.81\%$$

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

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

262 **Table 1. The Percentage Improvement in Voltage for The Dual Axis Setup Over the**
263 **Fixed PV Setup**
264

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

265 In Table 1, the average percentage improvement over the day is approximately 18.59%. This
266 means, on average, the Dual Axis Setup provides an 18.59% improvement in voltage over the
267 Fixed PV Setup throughout the day. This result shows that the Dual Axis Setup is significantly
268 more efficient than the fixed PV Setup, as it consistently produces higher voltage outputs
269 across all times of the day.
270

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

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

294

4. CONCLUSION

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

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