SolarTrack

ECE 445 Design Document - Spring 2026

Project # 7

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1 Introduction

1.1 Problem

With increasingly rising energy demands across the globe, societies are looking at renewable sources to power communities and prevent greenhouse gas emissions from climate change. For example, the International Energy Agency notes how solar photovoltaic generation is one of the most rapidly developing means of energy generation across the globe, but efficiency remains a key concern. Static solar panels only absorb the optimal amount of energy when the sun is shining perpendicular to the surface of the panel. However, the sun moves every instant of the day and in a different position at different times of the year. Thus, solar panels installed in fixed locations often operate far below their theoretical power generation capabilities. Power not harnessed is energy that could have supported homes, buildings, infrastructure, and necessary systems.

Energy efficiency isn't only a matter of improved environmental conditions, it's an economic opportunity and a matter of social benefits. If panels can absorb more energy, there's a reduced need for fossil fuels and a stabilized grid. Long term, financial output for consumers is lessened. From a social benefit perspective, increased use of renewable resources in systems provides cleaner air and fewer health concerns from soot and pollution. Furthermore, for developing countries or rural areas with minimal electrical infrastructure, supporting one solar installation to operate at maximum capacity increases potential for energy access and resiliency.

Energy efficiency also supports international efforts, like the United Nations Sustainable Development Goal 7, Affordable and Clean Energy. In stark contrast to that, commercial tracking systems are often monetarily expensive or too mechanically complicated to make them worthwhile. A solution must be sought that meets energy generation performance and reliability without sacrificing mechanical engineering prowess. Thus, a concept must bridge the gap by creating a system that can continuously adapt to environmental variables while remaining safe and stable.

1.2 Solution

The project detailed here attempts to create **SolarTrack**, a solar panel system that positions itself

to get the most energy potential through total light capture. Instead of a relative fixed mounting

setup, this system takes constant measurements of light intensity from varied angles and

uses servos to position itself. By tracking the sun as it moves, the project aims to increase power

output while providing a modular, scaled approach to smart, renewable physical infrastructure.

SolarTrack operates as an embedded system by combining sensing, computation, power and

actuation. Photoresistor sensors will notice different light intensities based on angles, and a

microcontroller will assess the differences and determine the ideal setup. The microcontroller will

send signals to dual axis servos that will move the system to get the solar panel in

the correct position. The position of the panel will also provide information to the microcontroller

through power monitoring capabilities of the power subsystem, which includes a voltage regulator

and power rails. The energy captured from solar panel will be fed through an energy

management portion which regulates battery charging and electronics use; all stabilized systems

will create a resilient unit with minimal human interaction thanks to a communications interface

for troubleshooting during development. All of these systems function as a closed loop control

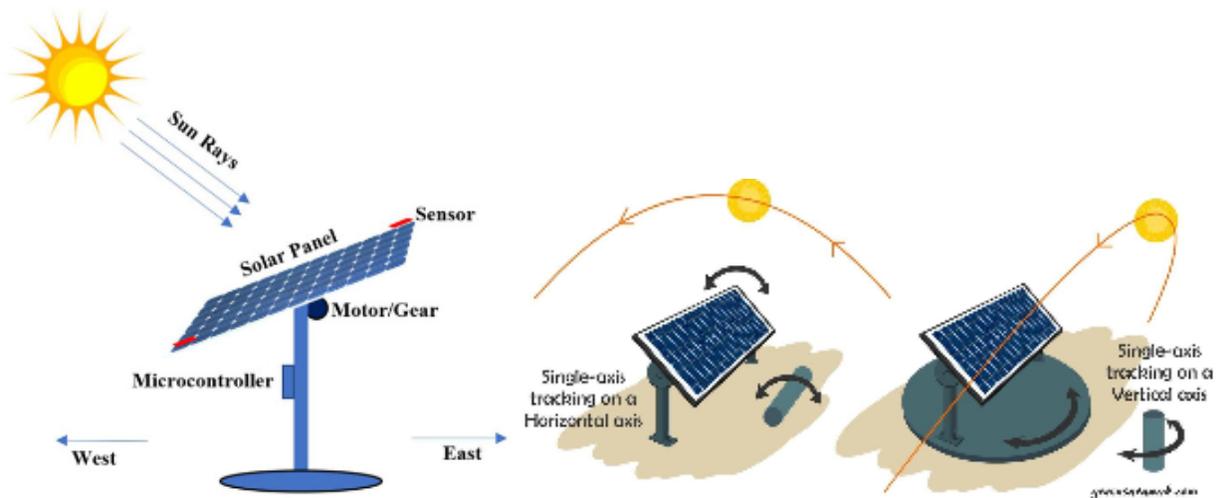system that operates essentially without outside interaction.

1.3 Visual Aid

Figure 1: Visual aid of a self positioning solar panel system

1.4 High-Level Requirements

For SolarTrack to be considered a success, Our self positioning solar panel system must

fulfill the following:

- The system must increase daily energy capture by at least 20% compared to a fixed

  panel under similar environmental conditions.

- The tracking mechanism must achieve angular positioning accuracy within ±10° to

  ensure the panel remains closely aligned with peak sunlight.

- The control system must complete orientation adjustments within 30 seconds of

  detecting a directional light imbalance to maintain efficient real-time tracking.

2   Design

2.1 Block Diagram
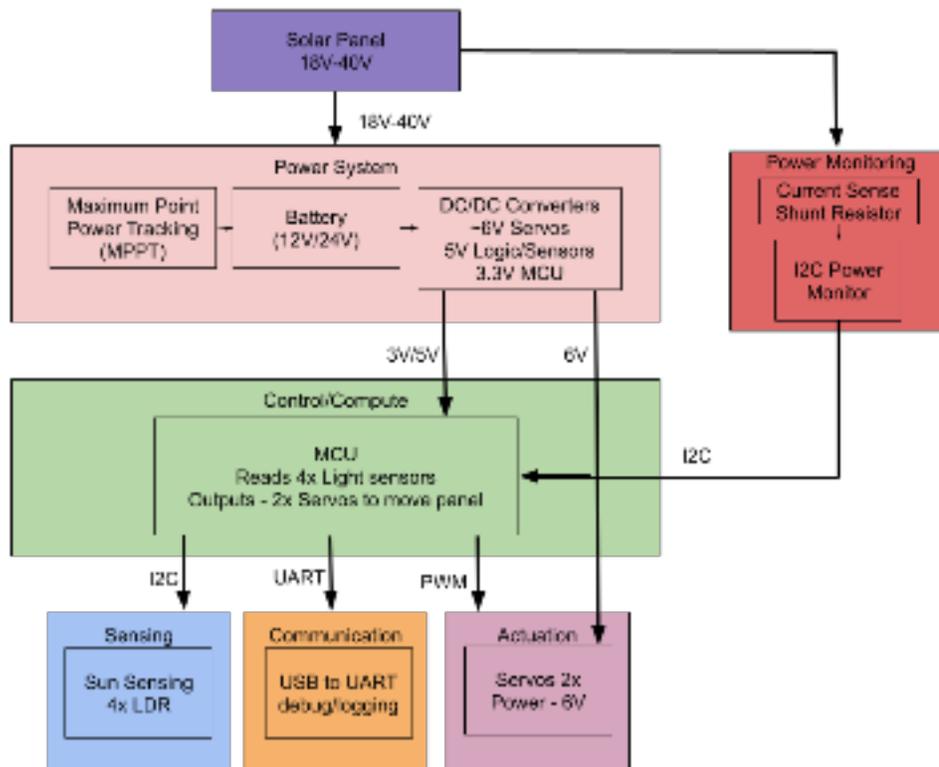
Figure 2: Block Diagram of Project

2.2   Subsystem Overview

2.2.1 Solar Panel

The solar panel is the main energy source. It produces a DC output ranging from approximately 18–40V that provides the raw energy used to run the electronics and servos. The panel's main purpose is to charge the battery through the Power System. Given that our project revolves around the optimization of the solar panel's energy capture, the solar panel itself is necessary to the design.

2.2.1.1 Interfaces with other subsystems

Charges the battery in the power system. Has its energy output monitored by the power monitoring system. Is repositioned as needed by the control/compute system.

2.2.2 Power System

This subsystem harvests energy efficiently, stores it, and generates stable rails for the rest of the design. It takes the variable energy from the panel as power and charges the battery. The power system also regulates voltage into 6V for servos plus logic rails for sensors and the MCU. Regarding the components of the power system: the battery is necessary for energy storage from the solar panel, and 12 volts is a fairly standard voltage that allows for flexibility with the various parts we will use. As we intend to run the entire system off the energy from the solar panel, MPPT is needed to optimize the battery's charging, improving efficiency <do we have a percentage?> The DC/DC converters are to adapt the battery voltage to that used by the remaining electronics.

2.2.2.1 Interfaces with other subsystems

The power system is used to power the control/compute subsystem. Charged by the solar panel.

2.2.3 Power Monitoring

To measure solar panel power, a small current sense shunt resistor is placed in series with the panel output, so the panel current creates a tiny voltage drop. An I2C power monitor measures that shunt drop to compute current and measures the panel voltage. The monitor sends the voltage and current readings to the MCU over I2C. There is not much to say about the technical details of the power monitoring subsystem, as it is fairly standard as far as design goes.

2.2.3.1 Interfaces with other subsystems

The power monitoring system monitors the energy output of the solar panel.

2.2.4 Control/Compute

The MCU runs the tracking algorithm. It reads four light measurements from the light sensors and computes the location with the most light by aggregating the data collected. The system then proceeds to commands two servos to move the panel until energy generation is optimized. The four light sensors are all pointed in different directions, providing the MCU with enough information to guess the true position of the light source. The two servo motors then allow the panel to rotate in the yaw and pitch axes of rotation. Servo motors are used because stepper motors, by design, must draw a small current at all times. As we want to maximize usable energy from the solar panel, servo motors are better, as they only draw current during rotation, and the panel will not be rotated frequently (rate less than 1 update per second.)

2.2.4.1 Interfaces with other subsystems

The control/compute system is powered by the power subsystem. It rotates the solar panel.

2.2.5 Sensing

This subsystem measures sun direction using four LDRs arranged so misalignment causes unequal readings and the system moves correspondingly. Since LDRs are analog devices, this block must produce voltages that can be converted into numbers by an ADC so the MCU can use them.

2.2.6 Communication

This is used to provide a wired debug/logging link to a computer. It lets you program the MCU, view sensor values, servo commands, and status messages during development and testing.

2.2.7 Actuation

This subsystem moves the panel mechanically in two axes. Each servo converts an MCU control signal into position/torque and relies on a regulated supply to move reliably. This system translates the data collected into mechanical movement of the panel.

2.3   Subsystem Requirements

2.3.1 Solar Panel

The solar panel is the primary energy source converting sunlight into electrical power that supports the tracking by continuously feeding the power system for charging and operation. It interfaces by supplying 18 to 40V to the MPPT. It also interfaces mechanically by mounting to the tilt structure while allowing full rotation without cable strain which will require strain relief and enough slack for motion.

2.3.1.1 Requirements

- Must provide 18–40 V at the MPPT input during normal operation.
- Wiring/connectors must be rated for 1.25x max panel current and 60V.
- Must tolerate open circuit or no load conditions without damage.
- Must be mounted and wired so full motion range does not stress or pinch cables.

2.3.2 Power System

The power system enables reliable self positioning by converting variable solar input into stable power rails and storing energy into the battery. It interfaces with the solar panel through an MPPT stage that accepts 18 to 40V and regulates charging into a 12 V or 24 V battery bus. It interfaces with other subsystems by generating regulated rails for electronics and actuation 6.0V for servos, 5.0V for logic/sensors, and 3.3V for the MCU.

2.3.2.1 Requirements

- MPPT must accept 18–40 V input and perform correct charging for the chosen battery.

- Battery bus must support the system voltage range 12 V or 24 V depending on chemistry.

- Must supply 3.3V to the MCU continuously.

- Must supply 6.0V to servos under motion and load.

- Servo rail capacity must support at least 2A continuous and 5A peak total.

- Must include undervoltage protection to prevent over discharging the battery.

- Must include protection against wiring faults like fuse and reverse polarity protection.

2.3.3 Power Monitoring

Power monitoring provides quantitative feedback on current, voltage, and power so the system can log performance and verify charging behavior. It interfaces electrically by inserting a precision shunt resistor in the battery bus to sense panel current and it interfaces digitally by reporting measurements to the MCU over a 3.3 V I2C bus with proper pull ups and a shared ground reference.

2.3.3.1 Requirements

- Must measure current up to the system's peak load without saturation (10 A).

- Shunt voltage drop at max current must be limited (target less than 100–200 mV) .

- Shunt power rating must safely handle I^2R at max current with margin.

- Must provide measurement updates at least 1 to 3 samples/sec for useful logging and fault detection.

- I2C interface must be 3.3 V compatible with correct pull-ups and shared ground.

2.3.4 Control/Compute

The MCU is the brain that self positions the panel by reading light sensor signals and commanding servo motion to align the panel for maximum sunlight. It interfaces with the sensing block via 4 ADC inputs, with the actuation block via 2 servo PWM outputs, with power monitoring via I2C, and with the communication block via UART for debugging/logging, all while being powered from a regulated 3.3 V rail that must remain stable.

2.3.4.1 Requirements

- Must operate from 3.3 V without resets during peak servo activity.
- Must sample 4 sensor channels at 10–50 samples/sec per channel.
- Must output 2 independent servo control signals with target jitter low enough to avoid servo twitch (50 microseconds).
- Control loop update rate must be 5–10 Hz so tracking is responsive and stable.
- Must support I2C at 100/400 kHz for power monitor data.
- Must support UART logging at least 115200 baud for debugging and validation.

2.3.5 Sensing

The LDR sensing subsystem provides directional sunlight feedback needed to maximizing solar energy capture. It does this by creating four analog measurements that indicate which direction is brighter so the MCU can steer the panel accordingly. It interfaces electrically by using four light dependent elements in divider circuits that produce four analog voltages within the MCU ADC range. It also includes analog filtering and software averaging to reduce noise that would otherwise cause noisy readings.

2.3.5.1 Requirements

- Must output 4 analog signals within MCU ADC limits (0–3.3 V).

- Must produce usable directional contrast at least 5–10% difference between opposing sensors when misaligned in sunlight.

- Must include filtering like RC or software averaging to prevent erroneous measurement.

- Must be mounted rigidly with consistent quadrant geometry.

- Divider components must be sized, so sensor outputs remain in range across expected lighting conditions.

2.3.6 Communication

The communication subsystem allows for debugging, calibration, and performance logging of sensor readings, power data, and servo commands during development and testing. It interfaces to a PC over USB and to the MCU over a 3.3 V UART at a defined baud rate of 115200 bps and it must share a common ground with the MCU.

2.3.6.1 Requirements

- Must provide UART at 3.3 V logic levels.

- Must support stable serial communication at 115200 bps.

- Must share common ground with MCU to ensure reliable signaling.

- Must avoid back powering between USB power and system power.

2.3.7 Actuation

The actuation subsystem physically moves the panel in two axes by converting MCU control commands into pan and tilt motion that maximizes sunlight exposure. It interfaces electrically by receiving a regulated 6V supply and by accepting two PWM servo control signals at 50 Hz and 1.0 to 2.0ms pulse width from the MCU, and it interfaces mechanically by coupling servo output

torque through brackets, gears, and linkages to rotate the panel through the required angular range.

2.3.7.1 Requirements

- Must operate from 6V under load.

- Power delivery must support at least 2A continuous and 5A peak total for two servos.

- Must accept MCU control signaling at 50 Hz and 1.0 to 2.0ms pulse reliably.

- Mechanical design must support required range of motion.

- Must prevent EMI noise from servo currents from resetting the MCU.

2.4 Requirements and Verification

Requirement	Verification
Must produce energy when exposed to direct light.	Hook up the solar panel's output to a voltmeter. Shine a bright light (a phone flashlight would suffice) incident on the solar panel and verify that a potential difference is observed.

Table 1: Solar Panel Subsystem Requirements and Verification

Requirement	Verification
Must provide sufficient energy for the entire system to be self-sustaining.	Once the other subsystems are assembled, provide the battery with a small charge and then let the system operate under normal circumstances. Ensure that over the course of a day, the battery gains charge –

	breaking even is not good enough, as it means there is no surplus.
Must provide a constant 3.3 Volt potential difference to the MCU.	Once the other subsystems are assembled, provide the battery with a small charge and then let the system operate under normal circumstances. Ensure that over the course of a day, the battery gains charge – breaking even is not good enough, as it means there is no surplus.

Table 2: Power System Requirements and Verification

Requirement	Verification
Must measure up to system's peak load without saturation.	In isolation, connect the subsystem to a current source, gradually increasing the current to 10 Amperes and verifying that operation remains consistent.

Table 3: Power Monitoring Subsystem Requirements and Verification

Requirement	Verification
Given input from four sensors, must output signals to the two motors to reposition the solar panel.	In isolation, connect the subsystem to four voltage sources that mimic the light sensors. Create realistic test examples representing various possible positions of the sun relative to the solar panel, populating the four voltage sources accordingly.

	Monitor the output of the subsystem and verify that the output does, in fact, align with the optimal output for the situation.
Light sensors must be mounted in four different directions, providing a clear difference between the sensors.	Once the sensors are placed, using a phone flashlight, test various angles (0 degrees / fully incident, 10 degrees, 20 degrees... 90 degrees) and distances (10 centimeters, 20 cm... 1 meter) and ensure that the signals from the four sensors are consistent with expectations and, when fed into the positioning algorithm, would rotate the solar panel toward the light source.
Must support debugging by logging through UART.	Ensure that the code includes various debug messages / print statements at various points in execution. Ensure that these messages are visible.

Table 4: Control/Compute Subsystem Requirements and Verification

2.5 Tolerance Analysis

A key tolerance risk is that the 4 LDR sensors may not create a large enough left/right or up/down voltage difference once you include resistor tolerances, ADC limits, and servo noise, which can cause wrong pointing. Each sensor is a divider: $Vadc = Vcc*(Rldr/(Rldr+Rf))$. Using Vcc = 3.3 V, Rf = 10 kohm, and Rldr = 5 kohm gives Vnom = 1.10 V. If one quadrant gets 10 percent more light, with R proportional to $E^{-0.7}$, then Rnew = 5k * $(1.1)^{-0.7}$ about 4.68 kohm and Vnew about 1.052 V, so deltaV about 48 mV. This means even 5 percent is about 25 mV. A 12 bit ADC at 3.3 V has 0.81

mV per count, so 25 mV is about 31 counts, well above quantization, and a few mV of tolerance or noise can be handled by RC filtering plus averaging.

2.6 Cost Analysis

The total cost for all parts as seen on the next page in Figure 3 before shipping is $300.67. 5% shipping cost adds another $15.03 and 10% sales tax adds another $31.55. We are using the services from the ECE machine shop for building our chassis. Estimating an hourly salary of $50/hr, we can also estimate the work and materials to take around 25 hours, which comes to $1,250. We can expect a salary of $40/hr x 2 hr x 60 = $4,800 per team member over the course of two months. Multiplying this with the number of team members, we get $4,800 x 3 =$14,400 in labor cost. Adding everything together, we arrive at a total cost of $15,997.25.

Description	Manufacturer	Quantity	Extended Price	Link
Solar Panel	LEPITERY	1	56.99	Link
60V Rated Wiring	Remington Industries	1	17.79	Link
Inline Fuse	YNZDRWA	1	7.18	Link
MC4 Connectors	BougeRV	1	9.99	Link
MPPT Charge Controller	Powerwerx	1	29.99	Link
SLA Battery	ExpertPower	1	24.99	Link
10A 40V Schottky Diode	Panjit International Inc.	1	0.9	Link
1000 µF electrolytic capacitor	Vishay Beyschlag	2	2.21	Link
10 µF ceramic (X7R) capacitor	Samsung Electro-Mechanics	8	0.3	Link
0.1 µF ceramic (X7R) capacitor	Samsung Electro-Mechanics	18	0.3	Link
Ferrite Bead	Eaton	1	0.1	Link
TVS Diode	Littelfuse Inc.	1	0.16	Link
220 µF electrolytic capacitor	Rubycon	1	0.39	Link
Current Sense Shunt Resistor	Ohmite	2	1.76	Link
I2C Pull-up Resistor: 4.7kΩ	Ohmite	4	4.68	Link
1 µF ceramic (X7R) capacitor	Taiyo Yuden	1	0.08	Link
0.012 µF ceramic (X7R) capacitor	Knowles Syfer	10	4.86	Link
ESP32-WROOM-32E-N16	Espressif Systems	1	5.71	Link
47 µF electrolytic capacitor	Rubycon	1	0.28	Link
3.3V regulator	Diodes Inc.	1	0.31	Link
6V buck converter	Pololu	1	31.95	Link
Pull-up resistor 10kΩ	YAGEO	10	0.1	Link
Push Button	Same Sky	2	0.2	Link
6-pin header	Würth Elektronik	1	0.35	Link
FT232 USB-to-UART bridge	FTDI	1	4.8	Link
USB-C Connector	Amphenol ICC	1	0.61	Link
Series register 22Ω	TE Connectivity Passive Product	2	0.1	Link
ESD Protection Diode array for USB	Texas Instruments	1	1.05	Link
Series register 220Ω	TE Connectivity Passive Product	2	0.2	Link
CdS photoresistor LDR 5mm	Advanced Photonix	4	6.16	Link
Heavy Duty Servo Motor	DFRobot	2	81.8	Link
XT60 Connector	SparkFun Electronics	1	2.5	Link
2200 µF electrolytic capacitor	Rubycon	2	1.07	Link
5.1kΩ resistors	YAGEO	1	0.2	Link
Servo Power Switching MOSFET	Toshiba Semiconductor	1	0.61	Link

Figure 3: Bill of Materials

2.7 Schedule

Week	Task	Person
24 Feb - 1 March	Breadboard 6V buck + battery power setup	Rahul
	Breadboard ESP32 + 3.3V regulator	Rahul
	Wire 1 LDR + ADC test	Rishikesh
	Write ADC reading + serial print	Rishikesh
	Wire single servo + PWM test	Sid
	Write PWM servo sweep test	Sid
	Calculate servo torque margin	Rahul
	Assemble temporary tilt bracket	Rishikesh
2 March - 8 March	Add all 4 LDRs to breadboard	Rahul
	Implement LDR differential comparison logic	Rishikesh
	Implement servo control algorithm	Sid
	Add filtering / averaging	Sid
	Combine sensing + actuation	Rishikesh and Sid
	Test tracking under lamp / flashlight	Everyone
	Tune tracking constants (avoid jitter)	Rishikesh
	Add deadband to prevent oscillation	Sid
	Add bulk capacitor to servo rail	Rahul
	Secure wiring / reduce noise	Rahul
9 March - 15 March	Breadboard Demo	Everyone
	Finalize PCB layout	Rahul
	Run DRC & prepare for PCB audit	Rahul
	Full firmware integration (ADC + PWM loop)	Rishikesh
	Bench test full control loop	Everyone
	PCB Order	Everyone
16 March - 22 March (Spring Break)		
23 March - 29 March	Receive & inspect PCB	Rahul
	Assemble PCB	Rahul
	Power rail bring-up (3.3V, 6V validation)	Rahul
	Flash firmware & test UART	Rishikesh
	Integrate servo + sensor hardware	Sid
	Identify hardware issues	Everyone
30 March - 5 April	Outdoor sunlight tracking test	Everyone
	Tune control loop (reduce oscillation)	Rishikesh
	Add failsafes (battery undervoltage, timeout)	Sid
	Servo noise suppression tuning	Rahul
	Prepare for Progress Demo	Everyone
6 April - 12 April	PCB Revision (if needed)	Rahul
	Final enclosure assembly	Rahul
	Improve logging & debug output	Sid
	Code cleanup & freeze	Rishikesh
13 April - 19 April	Full system validation (battery + MPPT + tracking)	Everyone
	Stress test servo load	Everyone
	Mock Demo Rehearsal	Everyone

Figure 4: Schedule

3 Ethics, Safety, and Societal Impact

Our project**, SolarTrack**, is designed to improve solar panel efficiency by actively tracking the sun's position throughout the day. This projects' objective aligns with the ACM Code of Ethics principle to contribute to society and human well being, as well as IEEE Code of Ethics Section I.1, which states that engineers must "hold paramount the safety, health, and welfare of the public." By increasing the amount of renewable energy captured from a solar panel, our prototype promotes more sustainable energy use and supports cleaner environmental goals. While SolarTrack is a prototype, its purposeembodies the idea of developing technology that benefit society without causing unnecessary harm.

Both ACM and IEEE emphasize avoiding harm and producing high quality work. Because our system involves electrical circuits, servo motors, and a rechargeable battery, improper design could result inthings like electrical shorts, overheating of components, mechanical instability while trying to move the panel, or battery problems. To uphold IEEE Section I.1 and ACM Principle 1.2 (avoiding harm), we will operate all components within manufacturer specified voltage and current limits, properly regulate power rails, and thoroughly test the system before use. Mechanical components will be secured and evaluated under expected torque and load to reduce the risk of structural failure.

Battery safety is another important ethical responsibility. Since SolarTrack uses a 12V battery system, improper charging or discharging could lead to overheating or fire. To follow IEEE's requirement to protect public safety and ACM's requirement of professional responsibility, we will follow safe battery handling procedures, ensure safe charging conditions, and prevent operation outside rated limits.

In addition, IEEE Section I.5 requires engineers to be honest and realistic in stating claims based on available data. We will therefore base all performance claims such as percentage improvements in energy capture on measured results rather than assumptions. We will also clearly cidentify and

show the limitations of our prototype including environmental factors that may affect tracking

accuracy. By following both ACM and IEEE ethical standards, we ensure that SolarTrack is not only

technically functional but also responsible, safe, and professionally developed.

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