SOLARTRACK

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1. Introduction

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.

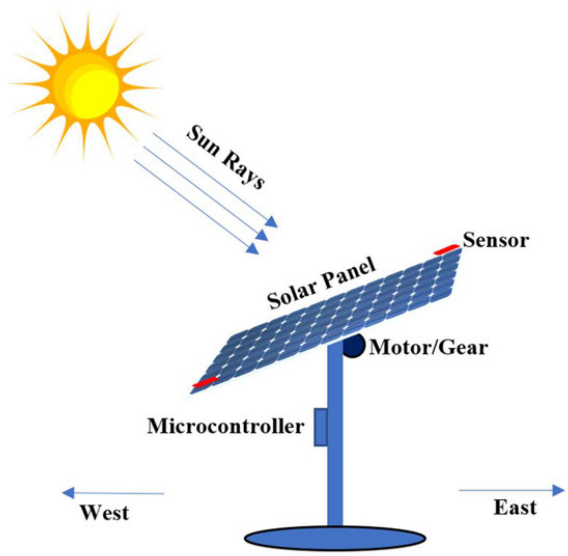
Energy efficiency isn't only a matter of improved environmental conditions; it's an economic opportunity and a matter of social benefits. If panels can absorb more energy, there's a reduced need for fossil fuels and a stabilized grid. Long-term, financial output for consumers is lessened; from a social benefit perspective, increased use of renewable resources in systems provides cleaner air and fewer health concerns from soot and pollution exposure. 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.

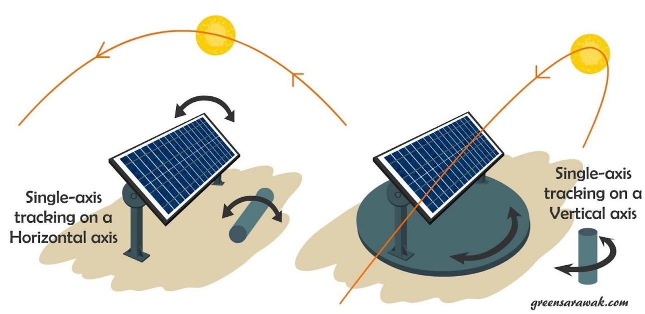
Energy efficiency also supports international efforts, like the United Nations Sustainable Development Goal 7, Affordable and Clean Energy. In stark contrast to that, commercial tracking systems are often monetarily expensive or too mechanically complicated to make them worthwhile. A solution must be 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.

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 actuated mechanical motion to position itself. By tracking the sun as it moves, it hopes 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 actuate the system to get the solar panel in the right 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.





High-Level Requirements

- 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

Block Diagram

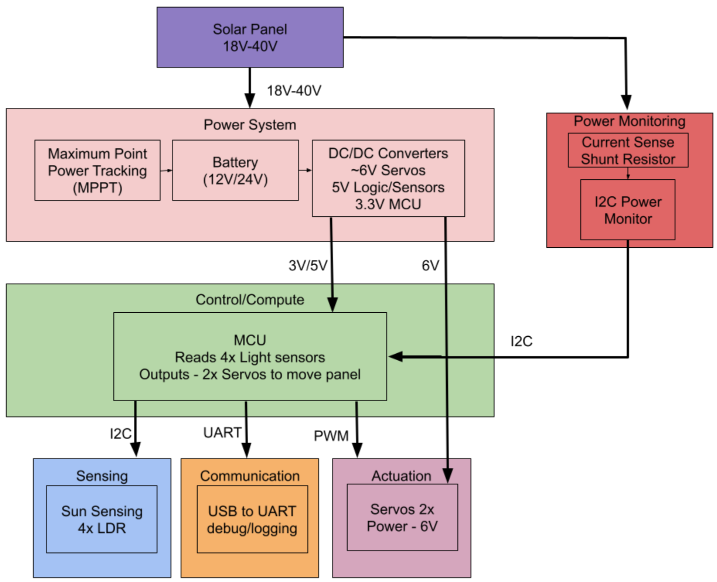


Figure 2. Block Diagram of Project.

Subsystem Overview

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.

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.

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 also measures the panel voltage.The monitor sends the voltage and current readings to the MCU over I2C.

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.

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.

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.

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.

Subsystem Requirements

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.

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.

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.

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.

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.

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 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.

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.

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 at least 115200 baud for debugging and validation.

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.

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.

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.

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.

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.

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.

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.

3. Ethics, safety and societal impact

The ACM Code of Ethics requires that we uphold certain standards in our work. Notably, we must work for the well-being of humanity and society. We must also respect the privacy of all, work towards producing high-quality work, and fulfill our social responsibilities as a team. Our project SolarTrack is based around a simple premise: maximizing the energy that a solar panel can capture throughout the day. Our intentions with this project are primarily focused on the public good and ensuring that we, as a society, can better utilize the cheap, renewable energy that solar panels can provide. As such, we already are striving for well-being with this project, and it does not pose a threat to the people. In general, the Code of Ethics also requires that we practice safety and ensure that we have knowledge of what we are doing, rather than blindly jumping into our work and risking doing a bad job or inadvertently injuring others in the process of assembling and testing our project. We intend to fulfill this aspect of our ethical responsibilities by following responsible lab safety practices as we develop and test our prototypes. Since we deal with batteries in this project (after all, the solar panel must charge a battery), we must use extra caution while handling the battery and make sure we always keep it in a safe environment to ensure that we meet all our ethical requirements.

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