Discussion – LDR and Photodiode Tracking System

The implemented light tracking subsystem combines **analog optical sensing** with digital control logic to orient the NEMA 17 motor toward the direction of maximum light intensity. The system employs a **pair of Light Dependent Resistors (LDRs)** and a **single photodiode (PD)**, arranged to capture lateral light gradients across the azimuth plane. This configuration provides a compact and cost-effective means of detecting angular deviations in sunlight, enabling the motor to maintain alignment with minimal energy consumption.

1. Principle of Operation

The photodiode acts as a **reference light intensity sensor**, measuring overall illumination levels incident on the tracking assembly. The LDRs, placed symmetrically on either side of the photodiode, sense the **relative light difference** between the left and right hemispheres of the field of view. Each sensor outputs a voltage proportional to the light intensity: brighter light reduces the LDR's resistance and increases the divider voltage, while for the photodiode's resistor-biased configuration, increased illumination raises the node voltage through a larger photocurrent across the 3 kΩ resistor.

These analog voltages are read through the **12-bit ADC** of the Arduino UNO R4, allowing for fine-grained measurement over a 0–5 V range. The system calculates the **differential light error**:

$$e = (V_R - V_{PD}) - (V_L - V_{PD}) = V_R - V_L$$

This simplification implies that the photodiode acts as a normalisation reference, compensating for global light fluctuations such as passing clouds or transient shadows. A positive error indicates stronger illumination on the right-hand LDR, prompting the motor to rotate right, while a negative error causes a leftward rotation.

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2. Signal Processing and Stability

Analog light sensors are highly sensitive to noise and instantaneous fluctuations. To ensure stable operation, each ADC channel undergoes **oversampling** (16 samples per read) followed by **first-order IIR filtering** with a smoothing constant α=0.25. This approach effectively reduces random jitter while preserving the system's ability to respond to slow changes in light direction.

A **deadband of 50 mV** and **hysteresis of 20 mV** were introduced to prevent oscillatory motion (hunting) when the light difference between the two LDRs is minimal. In practice, this means that minor imbalances caused by sensor mismatch or electrical noise do not trigger unnecessary motor activity. A **three-sample consistency check** further ensures that a rotation command is only issued when consecutive readings agree on the direction of light deviation.

After each movement, a **settling period** of approximately 250 ms is applied to allow sensor voltages to stabilise, preventing overcorrection or rapid direction changes. Together, these filtering and timing mechanisms produce smooth and deliberate tracking behaviour rather than oscillatory or jittery motion.

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3. Calibration and Offset Compensation

Although both LDRs share identical 10 kΩ resistor dividers, small differences in sensor characteristics, wiring, or lens alignment can lead to offset errors. To counteract this, the system incorporates a **calibration routine** that averages several hundred ADC samples while the rig is stationary and pointed toward a known light source. The routine computes the mean difference between the left and right LDRs and adjusts their voltage offsets such that:

$$(V_R - V_{PD}) = (V_L - V_{PD})$$

at the neutral (centred) position. This ensures that the tracker begins from an optically balanced reference, reducing long-term bias and improving accuracy under real sunlight.

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4. Motor Control Integration

The processed tracking decision (`Left`, `Right`, or `Hold`) directly informs the azimuth control module, which commands the NEMA 17 motor through the A4988 driver. The system allows discrete movement in **15° increments**, consistent with the motor's microstepped motion range (1/16 microstepping, 3200 microsteps per revolution). Each move is bounded between **0° and 270°**, ensuring the motor never exceeds its mechanical limits.

By combining **optical feedback** with **closed-loop angular control**, the subsystem achieves incremental but accurate realignment toward the maximum light direction, balancing **precision, stability, and energy efficiency**.

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5. Performance and Limitations

During testing, the sensor system exhibited good sensitivity under both indoor and outdoor lighting, with a voltage response range of approximately **0.3 V to 4.6 V** depending on light intensity. The normalised differential approach significantly improved robustness against global intensity changes; however, the system remains susceptible to **non-uniform shading** or reflections if one sensor is partially occluded.

The 15° motor step resolution introduces minor quantisation in alignment, but this was found to be an acceptable trade-off for reducing continuous motor activity and conserving power. For applications requiring finer angular precision, smaller step increments, or a continuous PID-based tracking scheme could be implemented.