Photo of Hardware

A 4.2 V battery-operated ATmega328P utilizes a raw sensor consisting of a dual LDR array and scales the sensor's output voltage down (≤ 1.0V) so it can be accurately read by the ADC (ADC Vref = 1.1V).

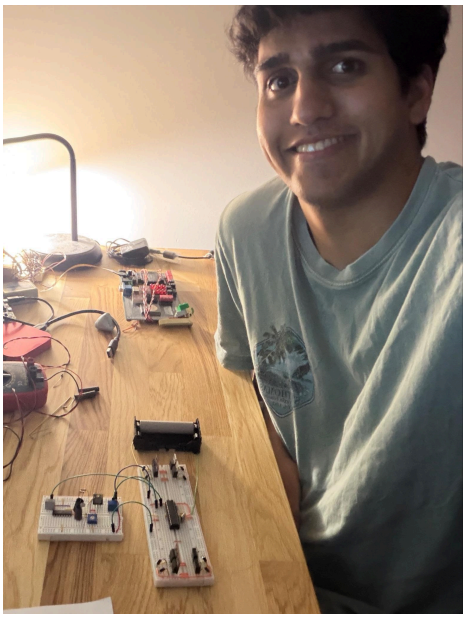


Figure 1: Me and my hardware

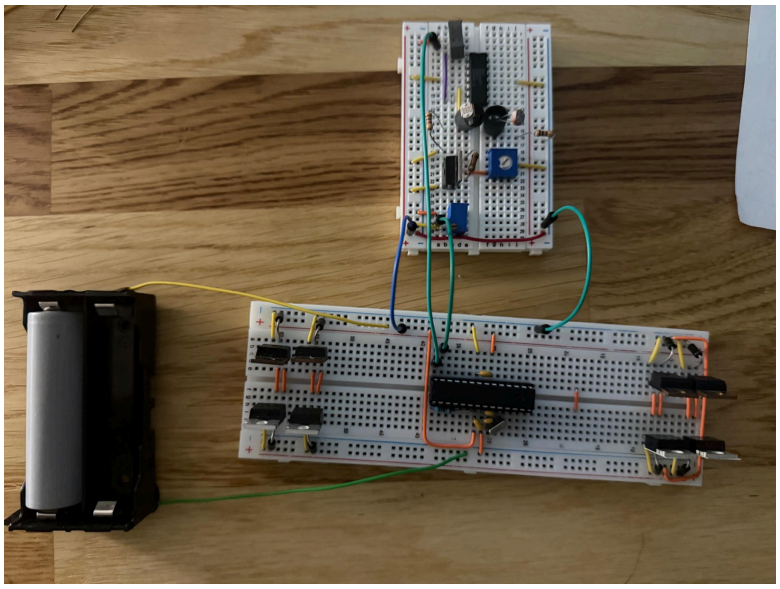


Figure 2: Closeup of hardware

Signal Processing Mountain

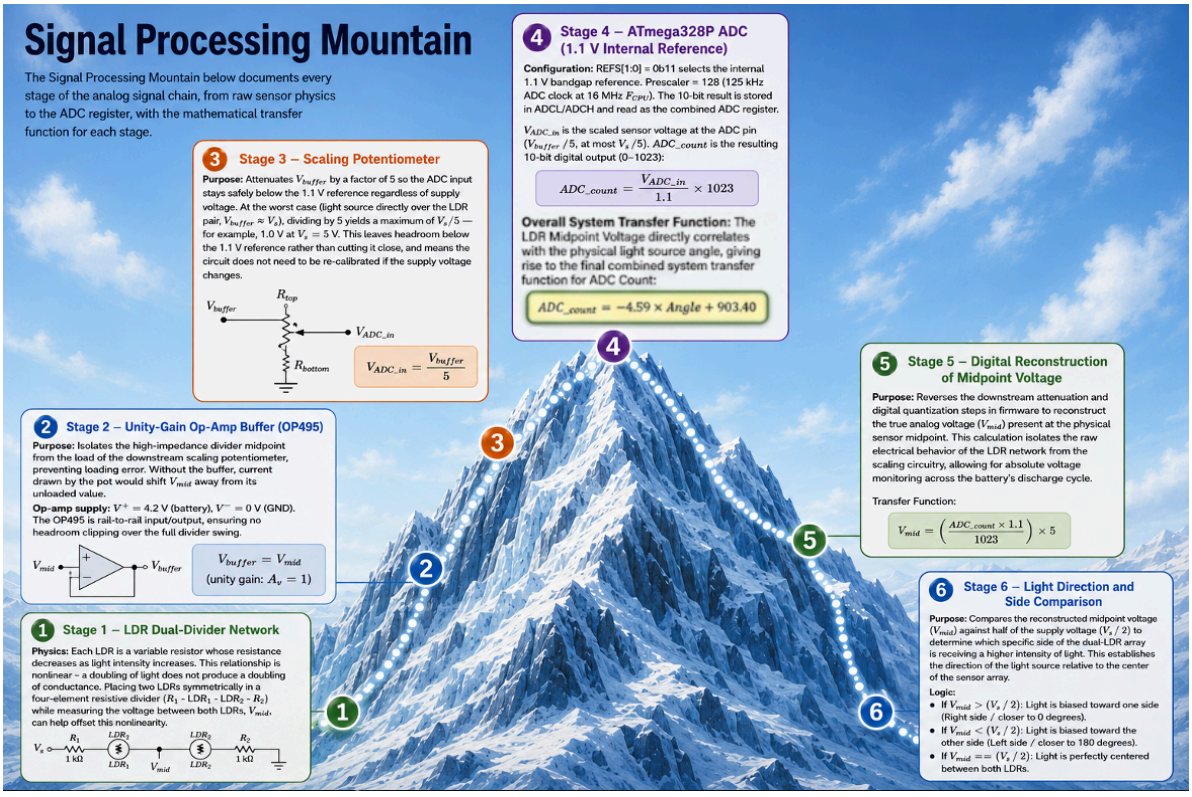


Figure 3: Signal processing mountain

Documentation of RAW Sensor

An LDR is a variable resistor. Its resistance decreases as light intensity increases, but the relationship is nonlinear. As a result, when the LDR is used in a voltage divider, the output voltage is a nonlinear function of light intensity. The general form of the single-LDR divider output is:

$$V_out = V_in \cdot R_fixed / (R_fixed + R_LDR)$$

Since R_LDR is a nonlinear function of light intensity, V_out is also a nonlinear function of light intensity. The dual-LDR arrangement and scaling was designed to correct this.

To make it linear, two LDRs are placed in a four-element divider (R_1 - LDR_1 - LDR_2 - R_2), and it measures the voltage between the two LDRs. This resulted in a linear relationship and was verified using a constant-brightness flashlight swept through five angles, recording the midpoint ADC value at each. The resulting values closely matched a linear trend across the sweep, supporting midpoint-vs-V_s/2 as a valid side indicator.

Angle is the independent variable being tested. ADC_count is the corresponding 10-bit LDR midpoint output (0 - 1023) read from the microcontroller, after the unity-gain buffer and divide-by-5 scaling described in Figure 3. The measured transfer function relating Angle to ADC_count is approximately linear over the tested range:

$$ADC_count = -4.59 \times Angle + 903.40$$

The negative slope reflects ADC_count decreasing as Angle increases from 0° to 180°. Comparing measured values to the fit, the largest deviation is at 45° (749 measured vs. 697 predicted, ~52 counts / 7.5%), with the rest within ~35 counts (under 8%) and 180° landing almost exactly on the line. Since angles were estimated by eye rather than measured with a protractor, this level of agreement supports treating the linearized response as reasonably accurate over the tested range.

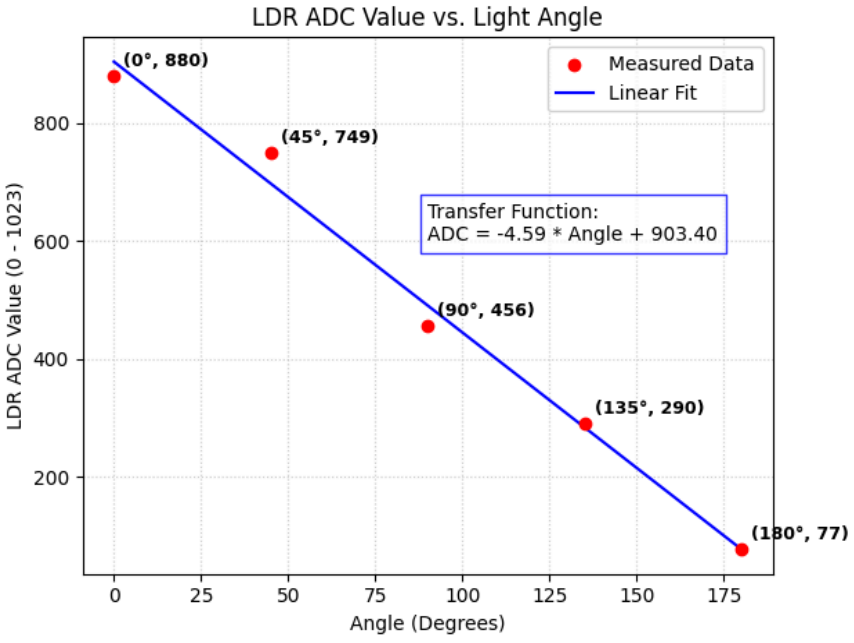


Figure 4: Transfer function of light angle vs. LDR ADC value

Technical Details and Justification for Signal Processing

To confirm the dual LDR system works correctly regardless of supply voltage, an LM317 regulator was used to vary the battery supply from 1.25 - 3.6V. At each tested voltage, with the flashlight held at 90°, the midpoint measured close to V_s/2 as expected, confirming the design holds regardless of supply voltage. The LM317 rig was used only for this validation step.

A 100 kΩ potentiometer divides the battery/supply rail by 5 into a separate ADC channel, the same scaling used for the LDR path. This currently measures supply voltage only, but will later be used to calibrate the system due to battery droop.

If V_battery were the ADC reference instead, V_bat_sense / V_ref would stay constant as the battery discharged, making the reading meaningless. Thus, using the internal 1.1 V bandgap avoids this. Sharing one battery between the ATmega328P and LDR requires the minimum voltage to be 2.7 V (minimum for the microcontroller to work) and the battery's 4.2 V full-charge maximum. Calibration is also needed for this project which is why divide-by-5 scaling so it can be measured by the ADC was chosen over fixed-voltage calibration. Typical current draw is ~5 - 10 mA (ATmega328P), ~1 - 2 mA (OP495 + LDR network), and ~9 mA combined giving the 3300 mAh battery ~2 weeks of runtime at this current stage.

Data Before and After Kalman Filter

A single-variable Kalman filter is implemented in firmware to smooth the raw 10-bit ADC readings. The filter maintains one state variable (the estimated ADC value) and updates it each time a new reading arrives, balancing trust between the running estimate and the noisy measurement.

Parameter	Symbol	Value	Rationale
Process noise	Q	0.001	Light level change slowly; small Q keeps the model trusted
Measurement noise	R	10.0	10-bit ADC has a lot of noise; larger R = more smoothing
Initial state estimate	x	512	Mid-scale starting guess (half of 0–1023 range)
Initial error	P	1.0	Low initial uncertainty

Table 1: Kalman filter parameters

With Q = 0.001 and R = 10.0, the filtered output tracks slow changes in light level while suppressing ADC noise. There is visible improvement and less fluctuation of the ADC value.

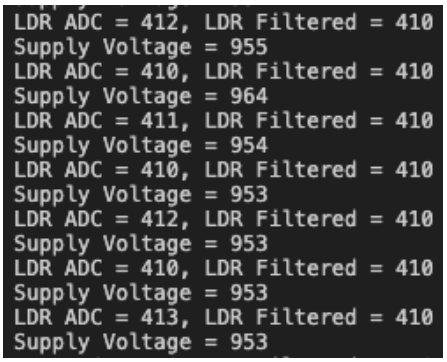


Figure 5: LDR ADC values before and after filtering

What I Learned This Week

I learned how to configure multiple ADC channels in bare-metal C and switch between them to perform independent calculations on different inputs before transmitting the values over UART. I also gained experience with the LM317 adjustable regulator and used it to verify if the dual-LDR network accurately maintains its midpoint voltage across varying supply levels though this component will not be part of the final design. Additionally, I successfully learned how to implement a single-variable Kalman filter algorithm in bare-metal C to smooth raw 10-bit ADC data and reduce high-frequency measurement noise.

AI Interactions

I utilized AI to assist in creating the Signal Processing Mountain graphic by providing a script and details of the individual signal chain stages to guide the image generation. I also used AI for conceptual verification and code reviews to ensure things like my Kalman filter implementation was correct and made sure to not use it to generate any source code. Lastly, I used AI as a reference tool to research common rail-to-rail operational amplifiers suitable for my project constraints.