Motor Voltage and Current Measurement System

Overview

To evaluate the electrical performance of the NEMA 17 motor during operation, the Arduino UNO R4 monitors both the **motor supply voltage** and **supply current** in real time. This allows the system to calculate instantaneous power consumption, detect load variations, and characterise energy efficiency under different motion profiles. The measurement system comprises two main sensing circuits: a **voltage divider network** for supply voltage sensing, and an **ACS712-05B Hall-effect current sensor** for current measurement. Data from both channels is read through the UNO R4's 12-bit analog-to-digital converter (ADC) and processed by a software-based telemetry module.

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1. Voltage Measurement

The voltage supplied to the motor driver (typically 12 V) cannot be directly connected to the Arduino's analog inputs, which are limited to a maximum of 5 V. To scale the voltage safely, a resistive divider network consisting of a **47 kΩ upper resistor (R_1)** and a **10 kΩ lower resistor (R_2)** was used.

The divider ratio is given by:

$$VADC = (Vin \times R2) / (R1 + R2)$$

Substituting the chosen values:

$$R2 / (R1 + R2) = 10k/(47k + 10) \approx 0.175$$

This means the voltage seen at the ADC input is roughly 17.5 % of the motor supply voltage.

For a 12 V system, the Arduino reads about 2.1 V, and the circuit can safely measure up to approximately 28 V without exceeding the 5 V ADC limit.

In software, the measured ADC value (0–4095 for a 12-bit ADC) is converted back to the true supply voltage using the inverse of the divider ratio:

$$V_{motor} = V_{ADC} * R1 + R2 / R2$$

This provides an accurate real-time representation of the motor's supply voltage.

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2. Current Measurement (ACS712-05B)

The **ACS712-05B** is a Hall-effect current sensor that measures the magnetic field generated by current flowing through its internal conductor.

This magnetic field is linearly converted into a proportional voltage output, providing **galvanic isolation** between the high-current motor line and the microcontroller input.

Key characteristics of the ACS712-05B include:

- **Sensitivity:** 185 mV/A
- **Zero-current offset:** approximately 2.5 V (midpoint of a 5 V supply)
- **Measurement range:** ±5 A
- **Output type:** Analog voltage (0–5 V range centred around 2.5 V)

When no current flows, the sensor outputs 2.5 V. Positive current (e.g., motor draw) raises the output voltage above 2.5V, and negative current (reverse direction) lowers it below 2.5V.

The instantaneous current is computed as:

$$I = (V_{out} - V_{offset}) / S$$

where:

- Vout is the voltage read from the sensor,
- Voffset=2.5V is the zero-current voltage,
- S=0.185V/A is the sensitivity of the ACS712-05B.

For example, if the sensor output reads 3.085 V, the corresponding current is:

$$I = (3.085 - 2.5) / 0.185 \approx 3.17\ A$$

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3. ADC Sampling and Filtering

The Arduino UNO R4's ADC converts each analog input to a digital value between 0 and 4095 (12-bit resolution). To improve accuracy and reject electrical noise from the stepper driver's pulse-width current chopping, each reading is oversampled 16 times and averaged in software. The resulting voltage and current samples are then passed through a first-order IIR low-pass filter defined as:

$$y[n] = (1 - \alpha)y[n - 1] + \alpha x[n]$$

With a smoothing constant of α =0.2

This technique produces a stable average reading while still tracking slow variations in motor power consumption.

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4. Power Computation

Once the instantaneous voltage (V_m) and current (I_m) are obtained, the electrical power consumed by the motor driver is calculated as:

$$P = V_m + I_m$$

This value represents the real-time power drawn from the supply line and can be used to analyse the motor's electrical efficiency or detect overload conditions during the 0–270° azimuth rotation.

5. Software Integration

A helper module named MotorTelemetry was implemented to handle sensor initialisation, oversampling, filtering, and unit conversions.
The module continuously updates and transmits the following telemetry data through the serial interface:

- Voltage (V)
- Current (A)
- Power (W)

This information is printed periodically (every 50 ms) while the motor is operating, allowing real-time monitoring or logging on a PC.
Each measurement can be calibrated by recording the sensor output at zero current to fine-tune the 2.5 V offset, ensuring accurate readings even when the system supply or temperature varies.