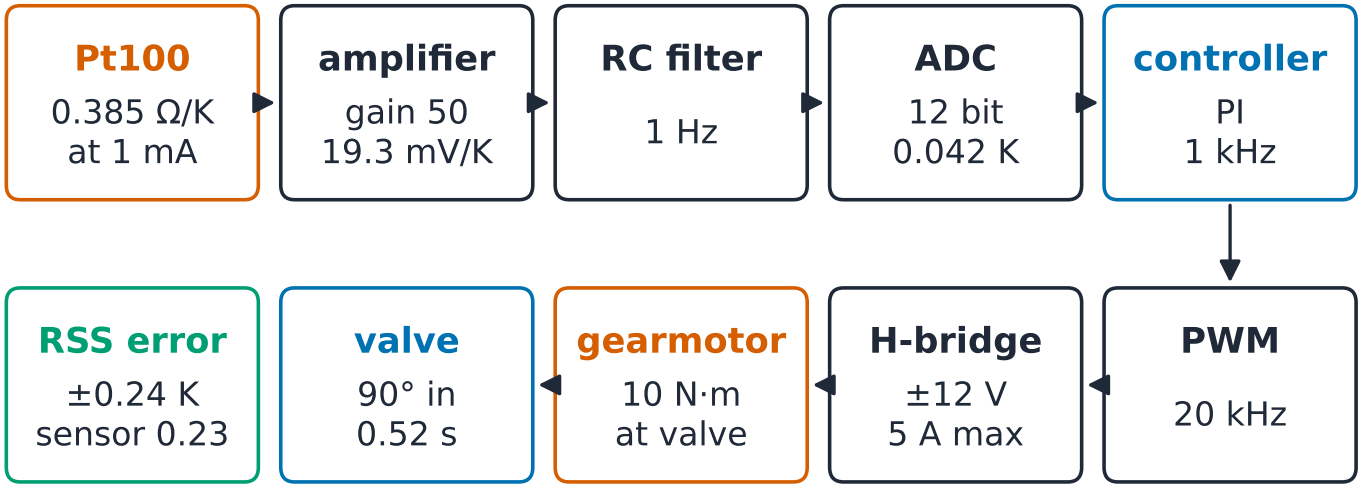
Exercise walk-through

12.6
Sensors and actuators

University Mechanical Engineering

The signal chain



Pt100 at 1 mA $\times$ 50 $=$ 19.25 mV/K; 12-bit **ADC** step $\mathbf{0.042}$ K; RSS budget $\pm\mathbf{0.24}$ K at 40 °C.

Error budget and actuator limits

1. **Sensor** Class A, $\pm(0.15 + 0.002\,T) = \pm 0.23$ K at 40 °C.
2. **Others ADC** 0.012, gain 0.04, self-heating 0.05 K.
3. **RSS** $\sqrt{0.23^2 + 0.012^2 + 0.04^2 + 0.05^2} = \pm\mathbf{0.24}$ K.
4. **Actuator** 12 V $\rightarrow \leq$ 4.78 rad/s; 5 A $\rightarrow$ 10 N $\cdot$ m; about 30 W at the motor.

Decision

A better ADC would change nothing; a better sensor would.

Exercises 2.1·2.2

2.1 Find the sensitivity at the ADC (mV/K), the temperature per ADC step (four decimals, K) and the rounding σ (four decimals, K). [3]

2.2 What voltage does a 0 to 100 °C range use, and why leave the rest of the 3.3 V unused? [2]

Exercises 2.1·2.2

2.1 Find the sensitivity at the ADC (mV/K), the temperature per ADC step (four decimals, K) and the rounding σ (four decimals, K). [3]

2.1

- $1\ \text{mA} \times 0.385\ \Omega/\text{K} \times 40 = \mathbf{15.4}\ \text{mV/K}$.
- Step $= 3.3/4096 = 0.806$ mV; $0.806/15.4 = \mathbf{0.0523}$ K.
- $\sigma = \text{step}/\sqrt{12} = \mathbf{0.0151}$ K.

2.2 What voltage does a 0 to 100 °C range use, and why leave the rest of the 3.3 V unused? [2]

2.2

- $V = \Delta T \times S = 100 \times 15.4 = \mathbf{1.54}$ V.
- Headroom for offset, drift and over-range (a fault reading above 100 °C should still be readable, not clipped).

Exercise 2.3

2.3 A 1 Hz RC filter sits before the ADC. Find its gain at 5 Hz (three decimals). [2]

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2.3

- $1/\sqrt{1+(5/1)^2} = \mathbf{0.196}$: 5 Hz noise is cut to about 20%.

Exercise 3.1

3.1 The chain of 2.1 measures water at 60 °C. Errors: a class B sensor, $\pm(0.3 + 0.005T)$; amplifier gain error 0.2% of the reading; self-heating at 2 mW/K with $R = 123.1\ \Omega$ at 60 °C; ADC rounding from 2.1. (a) Find each term (three decimals, K) and the RSS budget (two decimals, K). (b) Would a 16-bit ADC help? What would? (c) The valve actuator of sheet 12.2 delivers 0.314 N · m at the motor at 200.7 rad/s under load: find its shaft power, and give the limit set by voltage and the one set by current. [9]

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3.1

- (a) Sensor: $0.3 + 0.005 \times 60 = \mathbf{0.600}$ K.
- Gain: $0.002 \times 60 = \mathbf{0.120}$ K.
- Self-heating: $I^2R = (10^{-3})^2 \times 123.1 = 0.123$ mW, and $0.123/2 = \mathbf{0.062}$ K; ADC $\mathbf{0.015}$ K.
- RSS: $\sqrt{0.600^2 + 0.120^2 + 0.062^2 + 0.015^2} = \pm\mathbf{0.62}$ K.
- (b) No: the ADC term is already negligible. A class A (or 1/3 DIN) sensor, or calibrating it, attacks the dominant term.
- (c) $P = T\omega = 0.314 \times 200.7 = \mathbf{63}$ W.
- Voltage caps speed (24 V $\rightarrow$ 6.69 rad/s at the valve under load); current caps torque (6 A $\rightarrow$ 12.2 N · m at the valve).