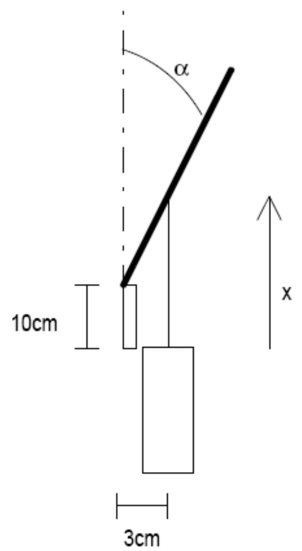

Figure 12.1: Angular position measurement system from Exercise 2.

Exercises

1. According to European standards, car speedometers must never indicate a speed below the actual speed, and the indicated speed must not exceed the actual speed by more than 10% of the actual value plus 4 km/h.

   (a) Let v be the actual speed and v_m the indicated speed. Plot the maximum and minimum admissible values of v_m as functions of v, together in the same plot.

   (b) Plot the maximum and minimum admissible values of v as functions of v_m, together in another different plot.

2. The angular position α in Figure 12.1 is measured using a laser sensor, able to provide readings in the $[100 \text{ mm}, 200 \text{ mm}]$ range, with a resolution of 1 mm and a precision of 5 mm.

   (a) What are the resolution and the precision in relation to the 100 mm width of the measuring range?

   (b) Show that the angular position α and the linear position x are related by

   $$\tan \alpha = \frac{d}{x - x_0} \tag{12.1}$$

   What are the values of d and x_0?

   (c) What are the maximum and minimum values of α that can be measured?

   (d) Plot $\alpha(x)$ for the entire possible ranges of both variables.

   (e) What is the precision in the measurement of α?

Table 12.1: Three accelerometers for Exercise 4.

	Servo	Piezoelectric	Piezoresistive
Range	10 g	10 g	10 g
Pass band	300 Hz	[1 Hz, 10000 Hz]	1000 Hz
Sensibility	1 mA/g	0.1 V s^2/m	5 μV/V/g
Precision	10^{-4} g	0.5%	1%
Price	1800 €	180 €	500 €

(f) What values can the resolution take?

3. The angular velocity ω of a rotating shaft is measured with an encoder that provides 1024 pulses per rotation, connected to a counter that uses a 5 Hz sampling frequency. The shaft can rotate up to 7500 rpm.

   (a) Show that the change Δn of the counter reading between two successive sampling instants is given by

   $$\Delta n = \lfloor 32.6\omega \rfloor \tag{12.2}$$

   when ω is given in rad/s.

   (b) Find the absolute value of the resolution of the angular velocity measurement.

   (c) Find the resolution in relation to the largest possible value of the angular velocity.

   (d) How many 4–bit counters are needed to make up a counter that can read all possible values?

   (e) If only the first 8 bits are considered, what will be the resolution of the angular velocity measurement?

4. An accelerometer is needed to measure accelerations in an automobile, in the [0 g, 2 g] range, with frequencies in the [0 Hz, 50 Hz] range, during 2 hours.

   (a) Which of the three sensors in Table 12.1 would you choose, and why?

   (b) The AD converter has 8 bits and an input in the [0 V, 5 V] range. Assuming that the power supply for the sensor will be the 12 V DC car battery, design the necessary signal conditioning.

   (c) What will the resolution be?

   (d) If data is recorded with a 250 Hz sampling frequency, how large will be the file where measurements are recorded?

5. A velocity sensor was tested for three different constant speeds. The time responses obtained are shown in Figure 12.2.

   (a) Do these time responses support that the sensor measurement is linear?

   (b) Find a suitable transfer function to model the sensor response.

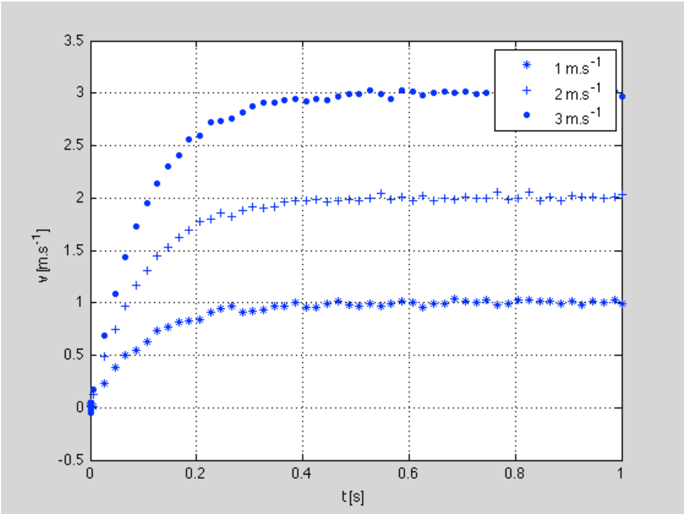

Figure 12.2: Time responses from Exercise 5.

6. An elevator comprises a 500 kg cabin, a 600 kg counterweight, and an electrical motor to move the steel cable that connects them. A 280 Ω extensometer, with sensibility $\frac{\delta R}{R} = 2$, mounted in a simple bridge powered at 24 V, measures the elastic deformation of the cable, given by (see Figure 12.3)

$$\varepsilon = \frac{F}{SE} \tag{12.3}$$

where the cable's cross-section is $S = 4\ \mathrm{cm}^2$, and the Young modulus is $E = 10^{11}$ Pa. The objective is to detect a cargo above the maximum admissible value of 150 kg.

   (a) Draw a scheme of the signal conditioning described.

   (b) What will the resolution be, in V/N?

   (c) Design an additional signal conditioning element to sound a buzzer when the cargo is too heavy.

7. The temperature of a motor can assume values in the $[10°\mathrm{C}, 180°\mathrm{C}]$ range, and is measured with an infrared sensor that works in the $[-18°\mathrm{C}, 538°\mathrm{C}]$ range. Its output is in the $[0\ \mathrm{V}, 5\ \mathrm{V}]$ range, and its precision is given by

$$\max\{4°\mathrm{C}, 2\%T_F\} \tag{12.4}$$

where T_F is the temperature measured, in °F.

   (a) Find the relation between the sensor output e and the temperature T.

   (b) What is the sensor's sensibility?

   (c) Given the range of temperatures being measured, what will be the actual range of e?

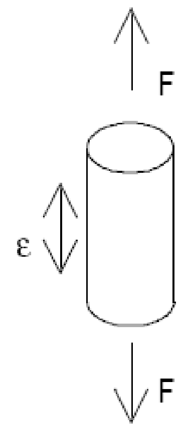

Figure 12.3: The elevator cable from Exercise 6.

(d) Plot the precision as function of T_F, in °F.

(e) Given the range of temperatures being measured, what will be the maximum value of the error?

(f) The sensor is directly connected to an 8–bit AD converter, that receives inputs in the $[0\text{ V}, 5\text{ V}]$ range. Find the AD output as a function of temperature.

(g) What will be the resolution of the measurement, in °C?

(h) AD converter noise affects 3 LSB. What will be the precision of the measurement, considering both conversion noise and sensor precision?

(i) The emissivity is 0.6, but estimated as 0.5. How will this affect precision?

8. A sensor outputs a tension in the $[0.2\text{ V}, 3.3\text{ V}]$ range, varying linearly with the relative humidity in the $[0\%, 100\%]$ range.

(a) Design the signal conditioning that will convert this output into the $[0\text{ V}, 1\text{ V}]$ range. Available tensions are 12 V, −12 V, and 5 V.

(b) This will be connected to a 10–bit AD converter that receives tensions in the $[0\text{ V}, 1\text{ V}]$ range. What is the resolution of the measurement?

(c) The precision of the sensor is 1% or less. What is the precision of the measurement, considering both the precision of the sensor and the resolution of the AD converter?

(d) Figure 12.4 shows a control system of relative humidity $H(s)$, where $H_{ref}(s)$ is the reference for humidity $H(s)$, $P(s)$ is a disturbance, $G_p(s) = \frac{100}{s+100}$ is the process we want to control, $G_s(s)$ is the sensor, and $G_c(s) = \frac{10}{s+10}$ is a controller. Find transfer function $\frac{H(s)}{H_{ref}(s)}$, and plot its Bode diagram.

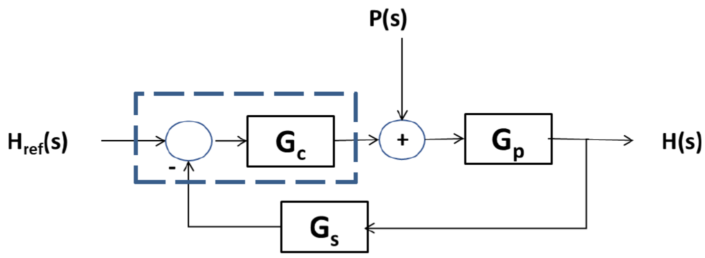

Figure 12.4: Relative humidity control system from Exercise 8.