Physical coupling

First step to embed a system into the real world:

Transform all kinds of physical phenomena into analogue voltages

- e.g. speed, pressure, brightness, loudness, colour, force, humidity, distance, salinity, density, radioactivity, spectrograms, reflectivity, acceleration, deformation, ..., ..., ..., or: temperature

Measuring temperature

Some observable effects of temperature changes:
- Mean square noise voltage changes
- Volume changes (gas, liquids, metals)
- Thermovoltage
- Changes in conductors and semiconductors
- State changes: into solid, liquid, or gaseous

Temperature measurement

• Take two wires (A & B) with different Seebeck coefficients $K_A$ & $K_B$
• Connect them on one side
• Place the connected side in one temperature zone, and the open ends in another
• Measure the voltage difference $U_{th}$

$$U_{th} = K_A(T_1 - T_2) + K_B(T_2 - T_1) = (K_A - K_B)(T_1 - T_2)$$

Thermoelements

$$E_{th} = K \cdot \text{grad}(T)$$

$$U_{th} = \int_{T_1}^{T_2} E_{th} dl = \int_{T_1}^{T_2} K \cdot \text{grad}(T) dl = K(T_2 - T_1)$$

some standard combinations: (typical shape: )

<table>
<thead>
<tr>
<th>short name</th>
<th>Material</th>
<th>$T_{max}$</th>
<th>$U_{th}$ with 0 to $T_{max}$</th>
<th>$K_A - K_B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(T)</td>
<td>Cu-Constantan</td>
<td>400°C</td>
<td>21.000 mV</td>
<td>42.5 x 10⁻⁸</td>
</tr>
<tr>
<td>(J)</td>
<td>Fe-Constantan</td>
<td>700°C</td>
<td>39.720 mV</td>
<td>53.7 x 10⁻⁸</td>
</tr>
<tr>
<td>(K)</td>
<td>NiCr-Ni</td>
<td>1000°C</td>
<td>41.310 mV</td>
<td>41.1 x 10⁻⁸</td>
</tr>
<tr>
<td>(S)</td>
<td>PtRh-Pt</td>
<td>1300°C</td>
<td>13.383 mV</td>
<td>6.43 x 10⁻⁸</td>
</tr>
</tbody>
</table>

all references and some links are available on the course page
The problem of heating the sensor itself

Application of the $P_{100}$ sensor:

The problem of heating the sensor itself

• $P_{100}$ in a TO18 enclosure:
  
  $R_{th} = \frac{T_{100} - T_e}{P_V} = 480\,\text{C} \cdot \text{W}$ in non-moving air

• limiting the sensor error to 0.5°C around 0°C ($R_s = 100\,\Omega$)
  
  
  $R_{th} = \frac{T_{100} - T_e}{P_V} = P_V = \frac{\Delta T}{R_{th}} = \frac{\Delta V}{R} = \frac{\Delta T}{R_{th}} = 0.323\,\text{V}$

• compensate for the non-linearity of sensor itself
• choose an adequate (bridge) circuit, e.g. a 'four wire' setup:
• keep the cables on the same temperature
• limit the influence of the sensor to the environment

More things to consider for the $P_{100}$ sensor:

• accepts high temperatures
• small
• relatively cheap
• also common as a Platinum wire around a glass or ceramics tube

Applications of standard thermocouples (cont.)

• (TYPE T) Copper-Constantan thermocouples are suitable for subzero temperatures with an upper temperature limit of 371°C and can be used in vacuum, oxidizing, reducing or inert atmospheres.
• (TYPE R) Platinum 13% Rhodium - Platinum thermocouples are suitable for continuous use in oxidizing or inert atmospheres at temperatures up to 1482°C.
• (TYPE S) Platinum 10% Rhodium - Platinum thermocouples are suitable for continuous use in oxidizing or inert atmospheres at temperatures up to 1482°C.
• (TYPE B) Platinum 30% Rhodium - Platinum 6% Rhodium thermocouples are suitable for continuous use in oxidizing or inert atmospheres and short-term use in vacuum atmospheres at temperatures up to 1700°C.
• (TYPE W) Tungsten - Rhenium alloy thermocouples are used to measure temperatures up to 2760°C. These thermocouples have inherently poor oxidation resistance and should be used in vacuum, hydrogen or inert atmospheres.

Applications of standard thermocouples

• (TYPE N) Nichrome-Nisil thermocouples are suitable for use in oxidizing or inert reducing atmospheres. Must be protected from sulphurous atmospheres. Very accurate at high temperatures. Virtually the same effect (electromotive force) and range as Type K.
• (TYPE J) Iron-Constantan thermocouples are suitable for use in vacuum, oxidizing, reducing or inert atmospheres. Suitable for measuring temperatures up to 760°C for largest wire size.
• (TYPE K) Chromel-Alumel thermocouples are suitable for continuous use in oxidizing or inert atmospheres up to 1260°C for largest wire size. Because their oxidation resistance characteristics are better than those of other base metal thermocouples, they find widest use at temperatures above 518°C.
• (TYPE E) Chromel-Constantan thermocouples are suitable for use up to 731°C in oxidizing or inert atmospheres for largest gauge wires. Type E thermocouples develop the highest emf per degree of all commonly used thermocouples.
• distances are measured along the optical axis only.

• highly focused light-beam required

• non-linear, very poor resolution, if...
Real-Time & Embedded Systems

Physical coupling

Range measurements – Triangulation

\[ d = b \cdot \tan \alpha \]

- projected point might be hidden → no measurement
- method is frequently used for measuring liquid levels.

Range measurements – Time of flight – Phase correlation

Method: measure the time of flight between the outgoing signal and the received reflected signal.

- in case of light, this method requires high resolution timers (> 1GHz)
- Method is perfectly linear.
- The achieved resolution depends on the precision of the signal’s rising edge and the resolution of employed timers.
- Signals can be formed and volume measurements are possible.

- in order to increase the resolution, the outgoing signals are often modulated and the phase shifts between outgoing and reflected signals are detected.

Range measurements: Ultrasound & Infrared

- in the special case of one ultrasound transducer for sending and receiving (like above), there is a short time delay before the transducer is ready to receive a signal (oscillations need to die away first).

Range measurements: Laser

A common laser range finder (SICK):
- range: max. 80m
- angular resolution: 0.25°
- response time: max. 53ms
- resolution: 10mm
- accuracy: typ. 5-10mm

Minimal reflectance versus maximal range

\[ f_d = -2f_v \frac{v}{c} \]

with source frequency \( f_v \), relative velocity \( v \) and signal speed \( c \).

Physical coupling

Summary

- Physical phenomena
- Measuring temperature
  - thermocouples, thermocouples
  - thermoresistors
  - thermistors
  - noise temperature measurement and others
- Measuring range and relative speed
  - triangulation
  - time of flight
  - intensity
  - Doppler methods
  - interferometry
- Examples: time-of-flight ultrasound & laser, Doppler current profiler