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Measurement Technology and Uncertainty Analysis - E7021E

Lab 3

Temperature measurement

Introduction

In this lab you are given a resistive PT100 temperature sensor. The task is to develop a model of temperature as function of the measured voltage. This includes designing a deflection bridge, calibrating the sensor, and doing the detailed uncertainty analysis of the complete system.

The experimental part of the lab should be done in pairs or in groups of three students. The report, however, should be *written* and handed in individually. Feel free to discuss results and prepare some figures in the group, but make sure you take the time to sit down on your own and formulate the main text of the report. For information on deadline, see the course web page. See guidelines for the report at the end of this document.

1 Preparations

These preparations should be done before the lab, and the results and MATLAB-code should be included in your lab report.

1.1 Homework assignment 1

You are given a file containing measurements of the function,

$$y[x] = a_0 + a_1 x + a_2 x^2 + n[x], \tag{1}$$

where $n[x]$ is white Gaussian noise.

Your task is to find the coefficients a_0, a_1, and a_2, so that your estimated polynomial,

$$\widehat{y}(x) = \widehat{a_0} + \widehat{a_1} x + \widehat{a_2} x^2, \tag{2}$$

is the best approximation (in a least-squares sense) to the given data. See MATLAB help of `polyfit` and `polyval` or estimate it using the matrix operations below:

$$\widehat{a} = \left(X^T X\right)^{-1} X^T y, \tag{3}$$

where

$$X = \begin{bmatrix} 1 & x_1 & x_1^2 \\ 1 & x_2 & x_2^2 \\ \vdots & \vdots & \vdots \\ 1 & x_N & x_N^2 \end{bmatrix}. \tag{4}$$

Then,

$$\widehat{y} = X\widehat{a}. \tag{5}$$

On the course web page you find a zip-file containing the data vectors `x` and `y`. Load this into your function using the command `load lab_prep_data`.

Your result should look something like Fig. 1.

1.2 Homework assignment 2

At the lab you will be given a Heraeus M-FK 422, PT100 temperature sensor (see attached data sheet). The PT100 sensor has a resistance of 100 Ω at $T = 0$ °C. The resistance changes with 0.385 Ω/K. The tolerance of the sensor is 0.5 %. This can be used to calculate the uncertainty, using $\sigma_{\mathrm{PT}} = h/3 = 0.5/300$ and treating the distribution as Gaussian.

The sensor is to be incorporated in a resistive deflection bridge. The task of this assignment is to design a suitable deflection bridge.

Make sure the current through the sensor is within the interval given by the data sheet. A lower current results in better performance, since it limits the self-heating of the sensor. Do not exceed 1.0 mA.

In your report, clearly state your assumptions and show the necessary calculations you made for the design.

2 Lab assignment

In the lab, we will provide samples of water with different temperatures as well as a reference thermometer. You can also mix tap water and measure the temperature with the reference thermometer to obtain additional measurement points for your experiments.

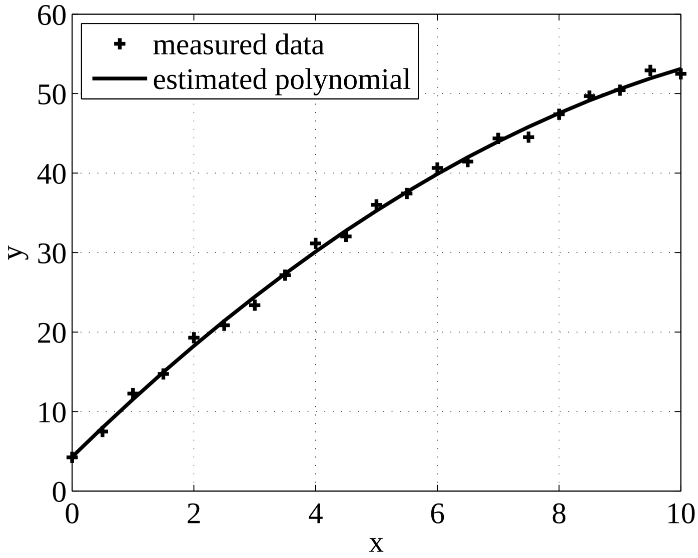

Figure 1: Data and fitted polynomial.

2.1 Experimental assignment

- Build the deflection bridge designed in the homework assignment.
- Connect the output of the deflection bridge to the lab amplifier (see Fig. 2).
- Measure the supply voltage at least 500 times during one minute. Estimate the mean and variance of the supply voltage.
- Use the water samples and the reference thermometer to measure the output of your system for at least 5 different temperatures (the more the better). For each temperature, capture at least 200 measurements (in a short time period).
- SAVE ALL YOUR DATA!

2.2 Theoretical assignment

- Estimate a polynomial model, relating the true temperature to the measured voltages.
- Perform a detailed uncertainty analysis of your system. Use the mean and estimated variance of the supply voltage, assume that the tolerance of the resistors in the lab is 1 %, and the tolerance of the PT100 sensor as given by the data sheet. All other components can be assumed to be perfect.
- Estimate the overall variance of your measured output.
- Based on the uncertainty analysis, how much of this variance is due to variations in supply voltage and how much is due to the tolerance of the PT100 element, as percentage of the full-scale deflection?

Present your results with relevant plots and tables of estimated values. Comment on the results! Do they match your expectations? If not, discuss the reasons. Also present all derivations of the uncertainty analysis.

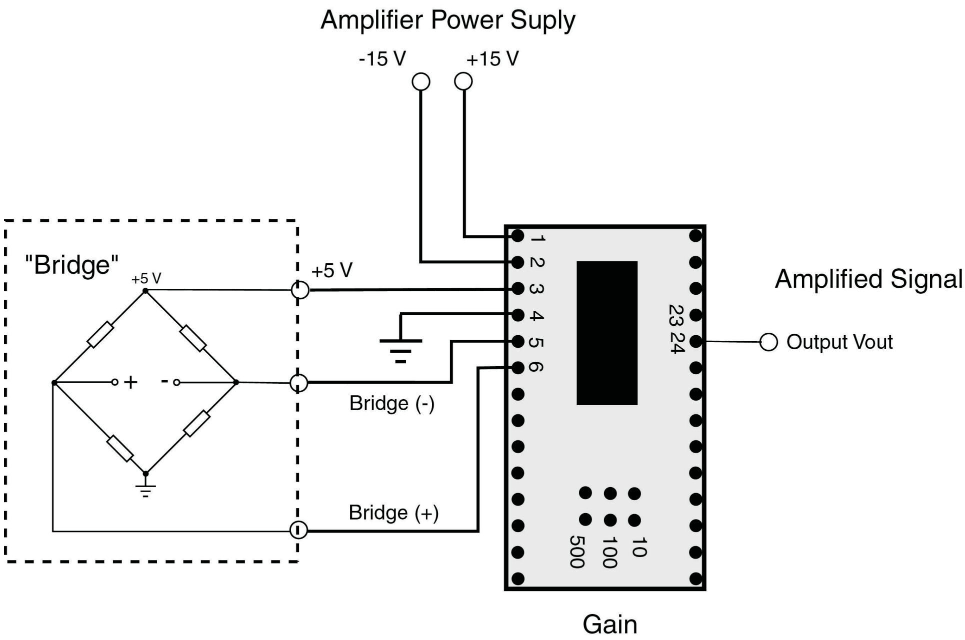

Figure 2: Lab amplifier connected to the deflection bridge.

2.3 Bonus assignment

This assignment is not mandatory. Do it if you have time.

- Prepare one container of water, with a temperature significantly different from the air temperature of the lab.
- Hold your sensor in air until the measured voltage is stable.
- While measuring, move the sensor from air to water (sample fast).
- What is the dynamic behavior of the sensor? Plot the response as function of time and discuss what you see. Try to estimate the time constant and order of your system?

3 Useful MATLAB functions

You can use the `help` command in MATLAB to get information on how to use the function. Below is a list of functions that may be useful for this lab:

- `polyfit` and `polyval`
- `errorbar`
- `mean` and `std`
- `plot`, `grid`, `xlabel`, `ylabel`, and `legend`
- `save`, `load`

In the file menu of each figure window, there is an "Save as..." function. Use this to save your figures, in for example .eps-format.

4 Writing the report

- Write the report so that a person who has not seen the lab instruction can follow the work flow and understand the purpose and all results.
- All figures axes should be labeled and all figures should have a descriptive caption.
- Comment on the figures. What do they tell you? Do they support the assumptions you made? If not, discuss why.
- The report should be written using a modern word processor. No hand-written math or figures will be accepted.