PT-100 Project

EE2802 — Machine Learning

Jaswanth Chowdary Madala (EE20BTECH11025)

IIT Hyderabad

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Contents

Introduction

Introduction

- The project is about using machine learning techniques to model the voltage-temperature characteristics of the PT-100
- In this project, we will apply Linear Regression using the least squares method to model the voltage-temperature characteristics of the PT-100 sensor

PT-100 Sensor

PT-100 Sensor

- The PT-100 sensor is a commonly used temperature sensor that is based on the resistance-temperature relationship of platinum
- The characteristic equation of voltage vs Temperature is given by the Callendar-Van Dusen equation

$$V(T) = V(0)\left(1 + AT + BT^2\right) \tag{1}$$

- The value of B is small. So by neglecting B, the curve can be modelled by a linear relation. Hence we have,

$$T = wV + b \tag{2}$$

Data Acquisition

Circuit Diagram

- The Circuit diagram that is used inorder to collect the data is shown in the below figure 1.

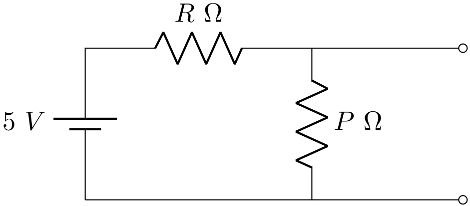

Figure 1: Circuit Diagram

Design Parameter R

- We want to read as many temperatures as possible. In order to do that

$$\max \frac{\Delta V}{\Delta T} \tag{3}$$

$$V = \frac{5P}{R+P} \tag{4}$$

- Lets say the minimum, maximum temperature we want to measure are T_{min}, T_{max} and corresponding PT-100 resistance is P_{min}, P_{max} respectively.

Design Parameter R

- Consider the following case,

$$T_{min} = -100^{\circ}\text{C} \quad T_{max} = 300^{\circ}\text{C} \tag{5}$$

The corresponding PT-100 resistance (from the data sheet) are

$$P_{min} = 60\Omega \quad P_{max} = 200\Omega \tag{6}$$

Design Parameter R

- $$\Delta V(R) = V(R, P_{max}) - V(R, P_{min}) \tag{7}$$
  $$\Delta V(R) = \frac{5 \times 200}{R + 200} - \frac{5 \times 60}{R + 60} \tag{8}$$
  $$\Delta V = \frac{700R}{(R + 60)(R + 200)} \tag{9}$$
  $$\Delta V = \frac{700}{\left(R + \frac{12000}{R}\right) + 260} \tag{10}$$
- By AM-GM inequality, we can get the optimal R

Design Parameter R

- To maximize ΔV, the optimal R is given by

$$R = 20\sqrt{30} \approx 110\,\Omega \tag{11}$$

Complete Circuit Diagram

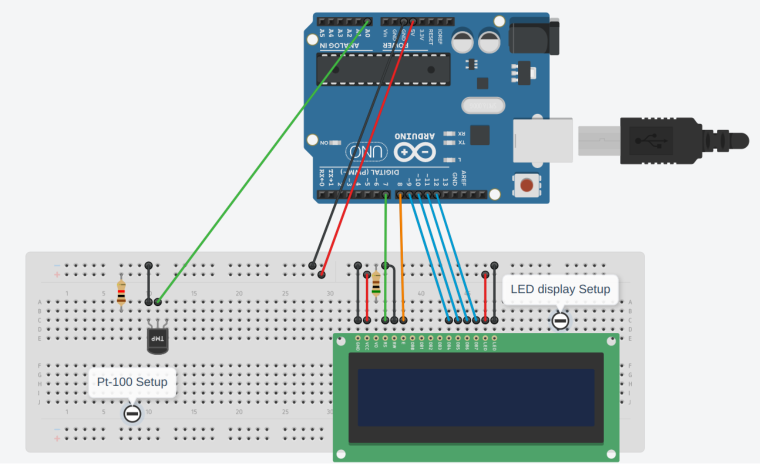

Figure 2: Circuit Diagram

Training Data

- The training data - Voltage reading of PT-100 collected from arduino and the Temperature reading collected from thermometer, is shown in the following table 1.

Voltage (in Volts)	**Temperature (in °C)**
1.70	30
1.74	40
1.75	45
1.79	53
1.82	62
1.85	71
1.88	80

Table 1: Training Data

Optimization

Least Squares Minimization

- For n data points $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$, the least squares function is the sum of squares of the difference between observed and predicted data values,

$$e = \|\mathbf{y} - \hat{\mathbf{y}}\|^2 \tag{12}$$

where

$$\mathbf{y} = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{pmatrix} \quad \hat{\mathbf{y}} = \begin{pmatrix} \hat{y}_1 \\ \hat{y}_2 \\ \vdots \\ \hat{y}_n \end{pmatrix} \tag{13}$$

$\hat{y_i}$ denotes the predicted value, y_i denotes the observed value

Linear Modelling

- The linear model is given by,

$$\hat{T}_i = wV_i + b \tag{14}$$

- For n data points, we have

$$\hat{\mathbf{T}} = \mathbf{V}^\top \mathbf{w} \tag{15}$$

where

$$\mathbf{T} = \begin{pmatrix} T_1 \\ T_2 \\ \vdots \\ T_n \end{pmatrix} \quad \hat{\mathbf{T}} = \begin{pmatrix} \hat{T}_1 \\ \hat{T}_2 \\ \vdots \\ \hat{T}_n \end{pmatrix} \quad \mathbf{V} = \begin{pmatrix} V_1 & V_2 & \dots & V_n \\ 1 & 1 & \dots & 1 \end{pmatrix} \quad \mathbf{w} = \begin{pmatrix} w \\ b \end{pmatrix} \tag{16}$$

Optimization Problem Formulation

- The optimization problem is given by

$$\mathbf{w}_{\text{opt}} = \arg\min_{\mathbf{w}\in\mathbb{R}^2} \left\| \mathbf{T} - \mathbf{V}^\top \mathbf{w} \right\|^2 \tag{17}$$

- This optimization probelem can be solved using numpy.linalg.lstq, gradient descent, cvxpy. The codes for the same is given. All .algorithms give the same result

Results and Testing

Linear Model Plot

- The plot of the training data, linear model curve is shown in the figure 3.

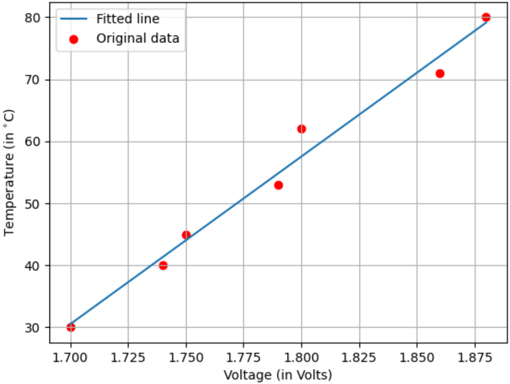

Figure 3: Model Training

Results

- The value of $\mathbf{w}_{\text{opt}}$ obtained from optimization is,

$$\mathbf{w}_{\text{opt}} = \begin{pmatrix} 270.28248588 \\ -428.99096045 \end{pmatrix} \tag{18}$$

- Finally this $\mathbf{w}_{\text{opt}}$ is fed to the arduino so that the temperature displays on the LCD screen

Testing

- The data used to evaluate the model is shown in the following table 2.

Voltage (in Volts)	**Temperature (in $^\circ$C)**
1.68	25
1.72	35
1.77	50

Table 2: Test Data

Linear Model Testing Plot

- The test data, linear model curve are shown in the figure 4.

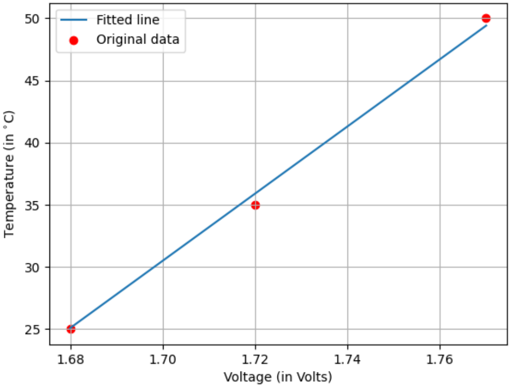

Figure 4: Model Evaluation

Conclusion

Conclusion

- In conclusion, this project effectively used machine learning to model the voltage-temperature characteristics of the PT-100, utilizing the least squares method and validating the model through test data.
- The project showcases the practical implementation of data collection and optimization.