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Techniques to linearise resistive sensors.

Chávez Hernández Carol Monserrat
ESCOM – IPN
cchavezh1900@alumno.ipn.mx

Moreno Martínez Diego Alejandro
ESCOM – IPN
dmrenom2002@alumno.ipn.mx

Giles Macias Alexis
ESCOM – IPN
agilesm1700@alumno.ipn.mx

Abstract – Resistive sensors are widely used in various applications to measure physical quantities such as temperature, pressure, and strain. However, the output of these sensors is often nonlinear, which can complicate signal processing and reduce measurement accuracy. This paper presents a comprehensive review of analogue way techniques to linearise resistive sensors.

Keywords – Wheatstone Bridge, Sensor, analogue, Thermistor, Operational amplifier.

I. Introduction

Wheatstone bridge circuits measure an unknown electrical resistance by balancing two legs one with the unknown component of a bridge circuit. These long-established circuits are among the first choices for front-end sensors. Whether the bridges are symmetric or asymmetric, balanced or unbalanced, they allow you to accurately measure an unknown impedance. Since bridge circuits are so simple yet effective, they're useful for monitoring temperature, mass, pressure, humidity, light, and other analogue properties in industrial and medical applications. [1].

Resistive sensors are semiconductors whose resistance values are strongly dependent on some physical field properties, this article talks about thermistors which are categorized based on their conduction models. Negative-temperature-coefficient (NTC) thermistors have less resistance at higher temperatures, while positive-temperature-coefficient (PTC) thermistors have more resistance at higher temperatures.

We've used an NTC thermistor to do this homework, this one can be viewed in the Figure 1 Usually, their resistance behaviour can be described by the Equation 1 Where the β parameter is in kelvins, and R0 is the resistance of the thermistor at temperature T0 (25 C = 298.15 K).

How much the resistance changes depends on the type of material used in the thermistor. The relationship between a thermistor's temperature and resistance is non-linear. A typical thermistor graph is shown in the Figure 2.

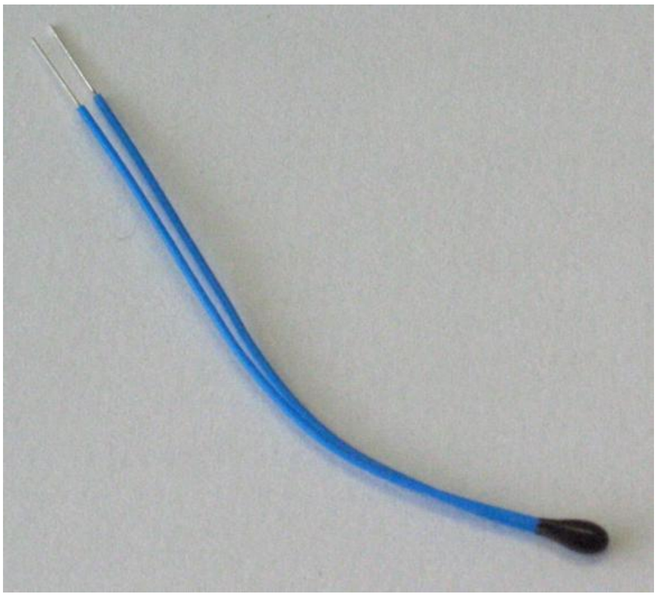

Figure 1 Negative-temperature-coefficient (NTC)

$$R = R_0 e^{\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)}$$

Equation 1 NTC thermistor's Characteristic equation

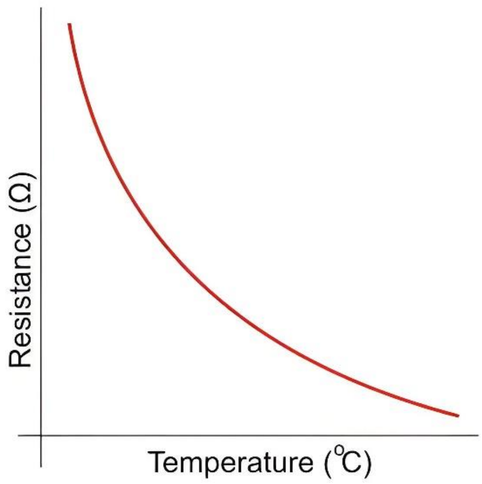

Figure 2 Thermistor's Characteristic graph

II. THE GOAL

The student will practically implement two linearization methods for resistive sensors, as well as their signal conditioning necessary in the design of a linear measurement system.

III. TOOLS USED FOR IT.

The following tools have been used to linearise the thermistor's behaviour.

- Two digital multimeters
- A DC voltage source
- Four Crocodile clips
- Eight Banana – Crocodile plugs
- A breadboard
- Two 10KΩ Resistors
- Two 1KΩ Resistors
- A 10KΩ NTC thermistor
- A 10KΩ potentiometer
- A LM35 temperature sensor
- A General-purpose Operational amplifier
- A lighter
- Cables for connecting

IV. CONTENT

Figure out the values of R_1 and R_2 in the Figure 3 considering the conditions that must be true for the Wheatstone Bridge to be balanced.

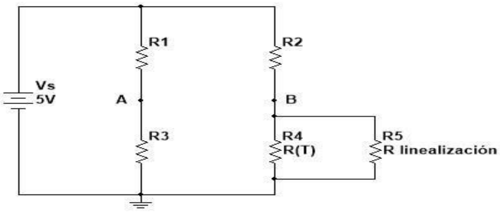

Figure 3

Before building the circuit, we got the thermistor's characteristic curve, this one can be shown by the Figure 4 and Equation 2.

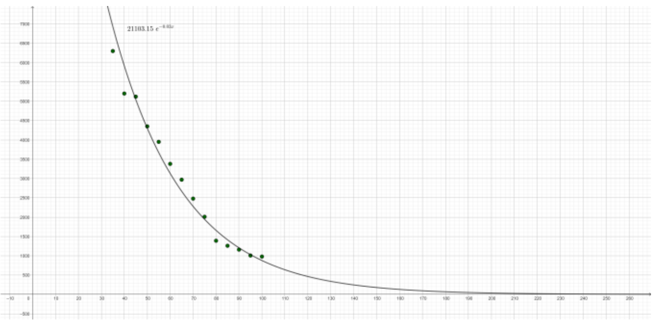

Figure 4 Characteristic curve

$$R(T) = 21103.15\ e^{-0.03T}$$

Equation 2 Thermistor equation

Ways to linearise NTC thermistor

Linearise Resistor

There are two basic ways to linearize a thermistor in hardware: voltage mode and resistance mode. For example, placing the thermistor in a voltage divider is considered voltage-mode linearization because the divider output voltage is directly used. Regardless, to translate voltage reading to temperature, an additional software linearization step is required. Sometimes, a thermistor is linearized to be used as a temperature-compensation resistor such as for LCD temperature compensation. This approach is called resistance mode linearization. However, improving thermistor linearity with series and parallel resistor combinations is at the expense of sensitivity. In these compensation applications, TMP61 may be a better alternative to NTC since TMP61 is already linear and sensitivity is more uniform across temperatures compared to the linearized NTC [2].

An example of a linearization circuit is shown in the Figure 5, the value of Rp was obtained in the last practice and its value is around 2974.048 Ω

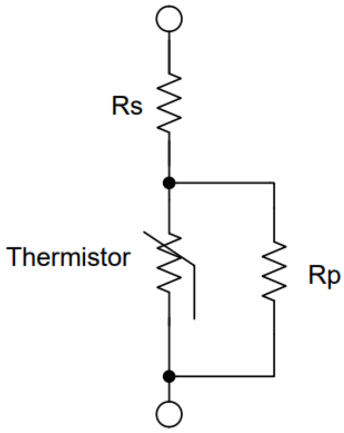

Figure 5 Linearization circuit example

The linear function is the parallel resistance between Rp and out of our thermistors, this function is shown in the Figure 6

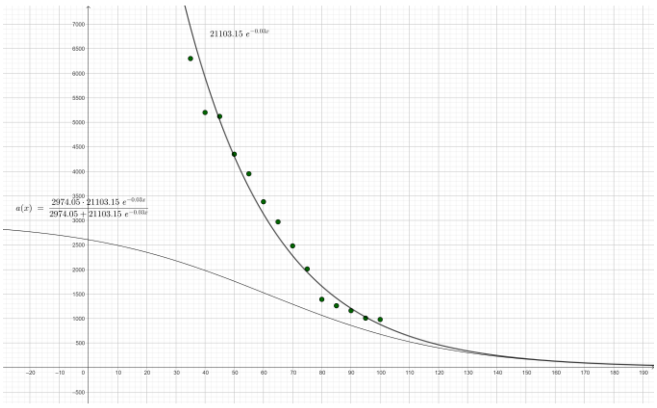

Figure 6

Using GeoGebra, after taking measurements with a digital ohmmeter we got the linear function shown in the

Figure 7

Temperature (ºC)	VA (Volts)	VB (Volts)	VAB (Volts)	Rt Calculated
30	3.437v	3.4v	-0.05 v	8130.44
40		3.411v	0.026 v	5916.11
50		3.373v	0.064 v	40304.86
60		3.114v	0.323 v	3132.43
70		2.606v	0.831v	2279.31
80		2.587v	0.880 v	1658.54
90		1.737v	1.7 v	1206.83
100		1.137	2.3 v	878.15

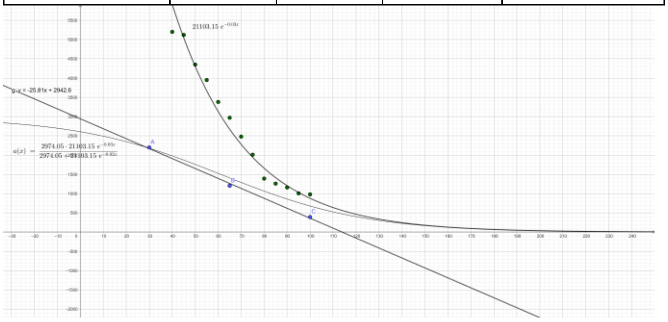

Figure 7 y = -25.81x + 2942.6

Temperature (ºC)	VA (Volts)	VB (Volts)	VAB (Volts)	Rt Calculated
30	3.437v	3.4v	-0.05 v	8130.44
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Table 1 Output voltages from the bridge

So, with this equation, we can tell the value of the equivalent resistance is near 2.2KΩ, for that reason the value of R_3 has been decided equal to that.

Besides that, the voltage in node A is always constant and equal to 3.4375V.

The left resistors have been decided at 1KΩ, so with these values, we can know the output voltage between A and B nodes, in the lower limit this is represented by the Equation 3 Meanwhile, the output voltage in the upper limit is represented by Equation 4.

$$V_{ab} = 5V\left(\frac{2200\Omega}{1000\Omega + 2200\Omega} - \frac{2198\Omega}{1000\Omega + 2198\Omega}\right) \approx -0.02173V$$

Equation 3 Output voltage in the lower limit

$$V_{ab} = 5V\left(\frac{2200\Omega}{1000\Omega + 2200\Omega} - \frac{390\Omega}{1000\Omega + 390\Omega}\right) \approx 2.0346V$$

Equation 4 Output voltage in the upper limit

After taking measurements with a lighter and looking at the current temperature with the LM35's output, some output voltages are shown by the Figure 8, Figure 9 and Figure 10 on the left side, there was a blue multimeter, which was measuring the output voltage from Wheatstone Bridge and on the right side there was a professional multimeter, that was reading the LM35's output voltage. You can note the output voltage from Wheatstone Bridge is negative, this is because the connection was inverted.

The Table 1 shows the results of this experiment.

Figure 8 Voltage at 50ºC

Figure 9 Voltage at 70ºC

Figure 10 Voltage around 90ºC and 100ºC

Finally, we got the function that creates a relationship between temperature and voltage, this is shown by Figure 11

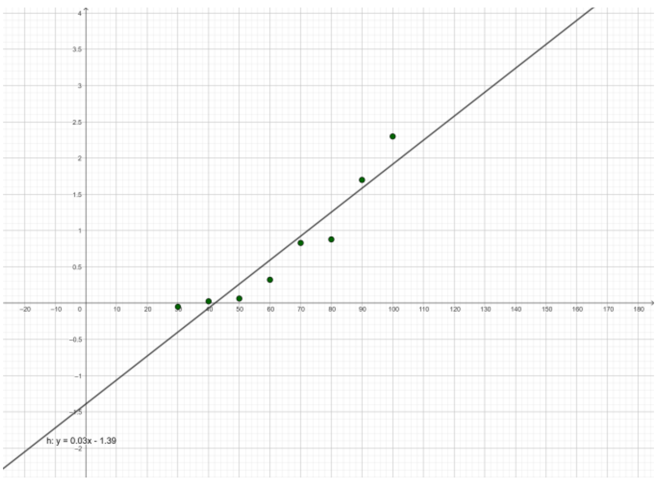

Figure 11 y = 0.03T - 1.39

Operational amplifier

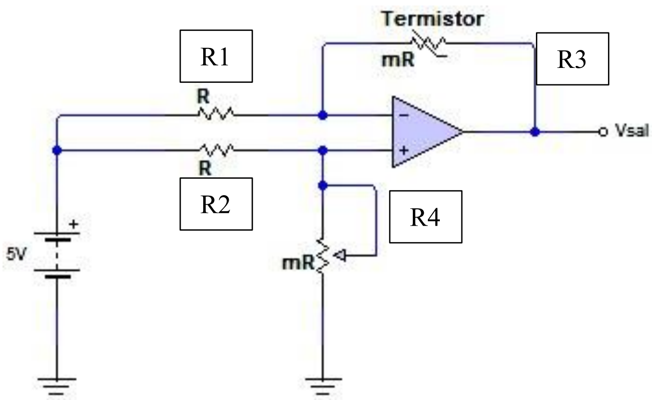

Figure 12 differential amplifier

$$V_{out} = V_2\left(\frac{R_4}{R_2+R_4}\right)\left(\frac{R_1+R_3}{R_1}\right) - V_1\left(\frac{R_3}{R_1}\right)$$

Equation 5 differential amplifier output voltage

$$V_{out} = \frac{R_3}{R_1}(V_2 - V_1)$$

Equation 6

The circuit in the Figure 12 is known as a differential amplifier, we do know that the output voltage in this setup in operational amplifiers is shown by Equation 5.

If $R_1 = R_2$ and $R_3 = R_4$ the output voltage becomes in the Equation 6, which means the output voltage will have a linear behaviour with slope $\frac{R_3}{R_1}$ for that reason R1, R2 and R4 will be of 10KΩ.

Afterwards, we took measurements we did the Table 2 which shows the differential amplifier's output voltage, results to be more linear than the Wheatstone Bridge, the equation obtained using GeoGebra is shown in

Thermistor Temperature (ºC)	Measured V_{SAL} (Volts)	Calculated Thermistor Resistance (Rt)
25	568 mV	8130.44
40	1.537 v	5916.11
50	1.820	40304.86
60	2.082	3132.43
70	2.189	2279.31
80	2.373	1658.54
90	2.44	1206.83
100	2.53	878.15

Table 2

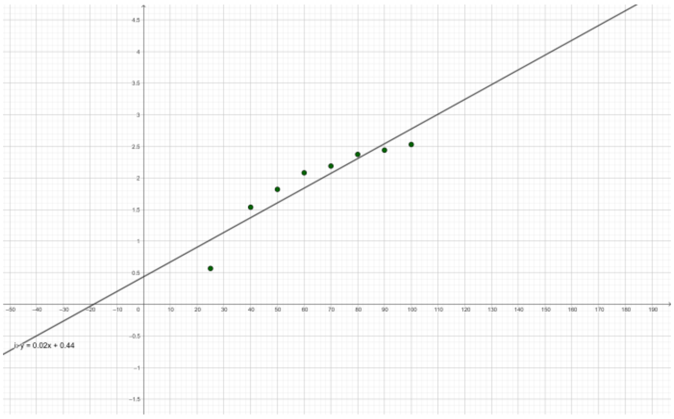

Figure 13 0.02T +0.44

V. QUESTIONNAIRE

1. Are the graphs obtained, for points 1 and 2 in this practice, linear? Why?

Yes, they are, because the Wheatstone Bridge offers a precision voltage, and the differential amplifier offers an output voltage with a slope that increases more and more when R3 decreases.

2. Which of the linearization methods is most advantageous to use? Because?

Wheatstone bridge, because it has no voltage leak and the operational amplifier can have a little bit of it because the rails can't offer the full voltage source, besides that the electric noise can increase when we're using an operational general-purpose amplifier, both methods can get better using precision resistors like 1%

3. Indicate another way in which linearization of a sensor can be performed, if not done at the signal conditioning stage.

Using software. For example, placing the thermistor in a voltage divider is considered voltage-mode linearization because the divider output voltage is directly used. Regardless, to translate voltage reading to temperature, an additional software linearization step is required. Sometimes, a thermistor is linearized to be used as a temperature-compensation resistor such as for LCD temperature compensation.

4. What should the equation look like for a linear V_{SAL}?

It should be like a linear function y = mx + b

VI. CONCLUSIONS

Chávez Hernández Carol Monserrat

I can tell that the choice between a Wheatstone Bridge and a Differential Amplifier depends on the specific requirements of your application. If you need high accuracy and simplicity, the Wheatstone Bridge is a great choice. However, if you require flexibility and ease of integration with digital systems, a Differential Amplifier might be more suitable.

Giles Macias Alexis

In conclusion, the linearization of resistive sensors is crucial for enhancing their accuracy and usability in various applications. This paper has examined multiple techniques, both hardware and software-based, for achieving linear output from resistive sensors. Hardware approaches, such as Wheatstone bridge configurations and feedback mechanisms, provide robust solutions but can add complexity and cost. Software methods, including polynomial approximation and digital signal processing, offer flexibility and can be implemented with existing digital infrastructure, though they may introduce computational overhead. Each technique has its own set of benefits and trade-offs, making it essential to choose the most appropriate method based on the specific requirements of the application. Future research should focus on hybrid techniques that combine the strengths of both hardware and software methods to achieve optimal performance in sensor linearization.

Moreno Martínez Diego Alejandro

Both the Wheatstone Bridge and Differential Amplifier are effective methods for linearizing resistive sensors, but they have different strengths and applications:

Wheatstone Bridge

Advantages:

- Accuracy: It provides high accuracy for sensor measurements, especially when used with precision resistors.
- Versatility: It can be used with various types of resistive sensors, such as RTDs (Resistance Temperature Detectors) and strain gauges2.

Disadvantages:

- Complexity in Calibration: Achieving high accuracy may require careful calibration and compensation for non-linearities.

Differential Amplifier

Advantages:

- Signal Conditioning: Differential amplifiers are excellent for amplifying the difference between two signals, which is useful for sensor linearization.
- Flexibility: They can be easily integrated into digital signal processing systems for further linearization and filtering.
- Ease of Implementation: Modern differential amplifiers are available in integrated circuit (IC) form, making them easy to implement in electronic designs.

Disadvantages:

- Cost: High-precision differential amplifiers can be more expensive than simple bridge circuits.

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