MINIMIZATION OF NON-LINEARITY IN TEMPERATURE DETECTORS USING ADAPTIVE TECHNIQUE

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ABSTRACT

Thermocouples being inexpensive transducer are widely used in industry. In thermocouple a reference junction is required to make an absolute temperature measurement, here temperature difference between two junctions are measured or indicated .But the problem arises, when it shows the non-linearity in its output characteristics. Up to a certain temperature it is seen that the thermocouple gives a linear output. At first output voltage from the respective junction' s temperature difference is increased with the temperature difference in a linear manner. Then after a certain temperature difference level , the output voltage is increased in a nonlinear way. This involves complications in order to measure the exact temperature difference. This paper aims at developing a new approach for linearization of thermocouple response i.e. constant sensitivity at all points of measurement. Here piecewise linear approximation technique which is different gradient or gain for different interval is applied. The aim of this work is to extend the linearity range of the thermocouple to get better stability and measuring technique under discrepancy of temperature coefficient . The sensitivity error can also be minimized by this novel technique

Keywords: Thermocouple, Transducer, novel technique, Linearization,

I. INTRODUCTION

Measurement of temperature using thermocouple widely required in process control system industries, though being popular for cost effectiveness, but finds difficulties in its uses when acquiring or measuring data over a wide span due to its nonlinearity in higher stage. Most of these ones rely on measuring some physical parameters that changes with respect to temperature. But in many applications, the sensor response should be precisely enhanced before the happening of further dispensation, for the reason that of low-level nonlinear response. In the past, multifarious analog conditioning circuits were used to precise the sensor nonlinearity.

These circuits often required physical calibration and precision resistors to attain the predictable accuracy. In modern days, however, sensor responses can be digitized directly. Linearization and calibration is then performed digitally, reducing the expenditure and the complicatedness.

Thermocouple is used to sense the temperature difference between its two ends. It produces the particular voltage when it senses definite temperature difference. In the anticipated linear world system it should also work as a linear control device. But the problem comes when it shows the non-linearity in its output characteristics . Up to a certain temperature it is seen that the thermocouple gives linear response. The output voltage from the respective temperature difference is increased with the temperature difference in a linear way at first. Then after a certain temperature difference level , the output characteristics changed in a non linear way.

So here in this work attempt is made to optimize this non-linearity problem as a better way by using multiple gradient calibration technique.

Software solutions for sensor compensation are surveyed. Complex hardwire system generally unable to rectify nonlinearity properly several digital technique also applied by the researcher to solve the problem.

In this report, a standard technique is being approached for the linearization of sensor where nonlinear curve is assumed is a sum of different linear area.

In 2005 Russell Anderson, Thomas Kugelstadt showed in their paper ' Thermocouple Measurements with DS ADCs and the output characteristics of the thermocouple comparing the See beck Voltage. But there also the non-linearity problem remains. In the OMEGA booklet it is also discussed a idea to rectify non-linearity but not able to give the optimum solution .Rather RICHARD M. PARK showed the detailed mechanism about the problem of nonlinearity in his book ' Thermocouple Fundamentals.

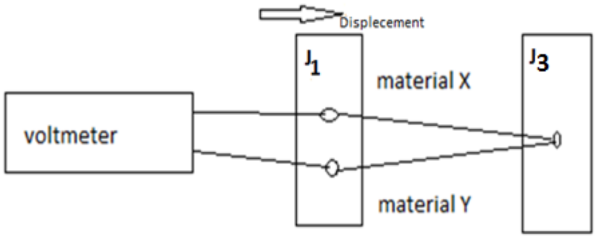
So here my intention is to rectify this non-linearity problem by using the multiple gradient calibration technique which is based on assumption that nonlinear curve is the sum of several linear curve. So that it will be more accurate and successful in order to optimization.

II. MATERIALS AND METHODS

MATHEMATICAL MODEL

The transfer function of many Sensors contains nonlinear factor. In most of the cases nonlinearity is small enough to be ignored. However in many sensors this factor must be taken into account .In such cases different Compensation techniques are applied to optimize such nonlinearity. Thermocouple shows nonlinearity in output voltages with respect to temperature variations.

The Physical representation of thermocouple is shown here in the figure bellow. Thermocouple output characterization based on See back effect. Taking into account See back coefficient σ which is an inherent property of the substance is nonlinear with respect to temperature variations.



We can write the See beck Coefficient equation as follow:

$$\sigma(t) = lim_{\Delta t \to 0} \frac{\Delta V}{\Delta t}\} \text{...........(1)}$$

$$\Delta V = Change \in induced E.M.F.$$

Now using the Fundamental Theorem of Calculus, the limit becomes a derivative and we can write: $\sigma(t) = \frac{dV}{dt}\}$ ....(2) Equation (4.2) can be applied to the equation (4.1) by writing

$$d(V) = \sigma(t)d(t) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \text{(3)}$$

Thus, the EMF generated in material A between the junction at T_t and the junction at T_j is

$$V_{a,J3} = \int_{J_1}^{J_3} \sigma_a(t)dt \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \text{(4)}$$

ANALYTICAL MODEL

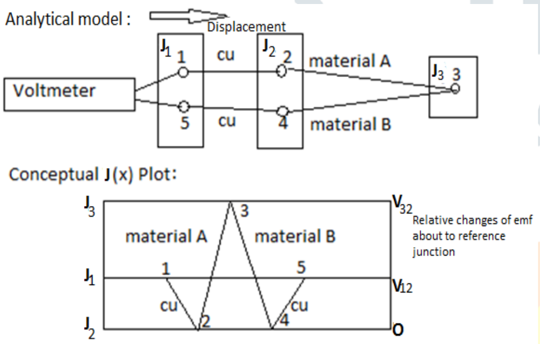


Fig.1. Relationship Between Temperature And Thermocouple

Now we have to find the E.M.F. produced by the Thermocouple circuit in Fig. 2. So apply the Equation (4) to each segment of the wire in the circuit and get Eqn (5)

$$V_{15} = \int_{J_1}^{J_2} \sigma_c dt + \int_{J_2}^{J_3} \sigma_A dt + \int_{J_3}^{J_2} \sigma_B dt + \int_{J_2}^{J_1} \sigma_c dt$$

Where σ_C is the absolute See beck coefficient of copper, σ_A is the absolute Seebeck coefficient of the material in the positive leg, and σ_B is the absolute See beck coefficient of the material in the negative leg. Reversing the limits of integration for the first term in Equation (5) gives [21]

$$\int_{J_1}^{J_2} \sigma_c dt = -(\int_{J_2}^{J_1} \sigma_c dt) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots$$

(6)Therefore, the first and last terms in Equation (4.5) cancel. Furthermore, reversing the limits of integration in the third term in Equation (4.5) and simplifying yields

$$V_{15} = \int_{J_2}^{J_3} \sigma_{AB} dt \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \text{(7)}$$

Where $\sigma_{AB} = \sigma_A - \sigma_B$

The integral is never directly evaluated. Instead a polynomial curve fit to the data gives

$$V_{03} = f(J_3) = A_0 + A_1 J_3 + A_2 J_3^{\,2} + \cdots + A_n J_3^{\,n} \ldots \ldots \ldots \ldots \ldots \ldots \ldots$$

This is the equation on which the total work in this paper is done. Equation (8) here is the equation of the primary signal or the output of thermocouple that is V_{o3} at temperature j3. Now the non-linear output of thermocouple or equation (8) is simulated using Mat lab shown in the Fig 4.Here we can clearly see that the output voltage is not linearly changed with the increase of the temperature difference.

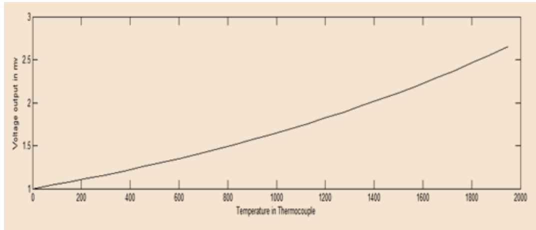


Fig.3. Non-linear Output of Thermocouple

THERMOCOUPLE RESPONSE RECTIFICATION

Optimization of the nonlinear characteristics of thermocouple done using piecewise linear approximation technique .Here nonlinear characteristics of thermocouple is approximated as sum of multiple no of straight lines with different gradient. a J type thermocouple is taken for said experiment.

Thermocouple voltage at different temperature are noted from reference table [10].Now a look up table is formed with thermocouple output voltage range for particular temperature span and corresponding gradient (mv/°C) for that temperature range. A gap of 10 degree & corresponding voltage is noted. Smallest division Sa y 5 or less degree may be taken for more accuracy.

Gradient m= (difference of voltage of the belonging range)/(difference of temperature of the belonging range)

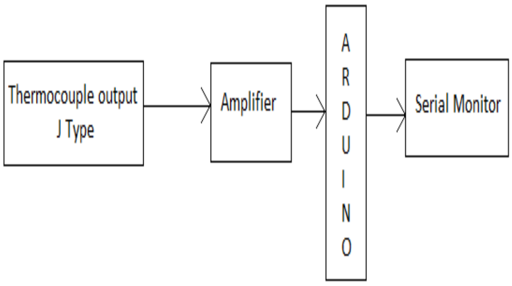
for 1st range m1= (2.059mv-1.537mv)/(40-30) °C

2nd range m2= (2.585 mv -2.059 mv)/(50-40) °C

3rd range m3= (3.116 mv -2.585 mv)/(60-50) °C

9th range m9= (6.360 mv -5.814 mv)/(120-110) °C

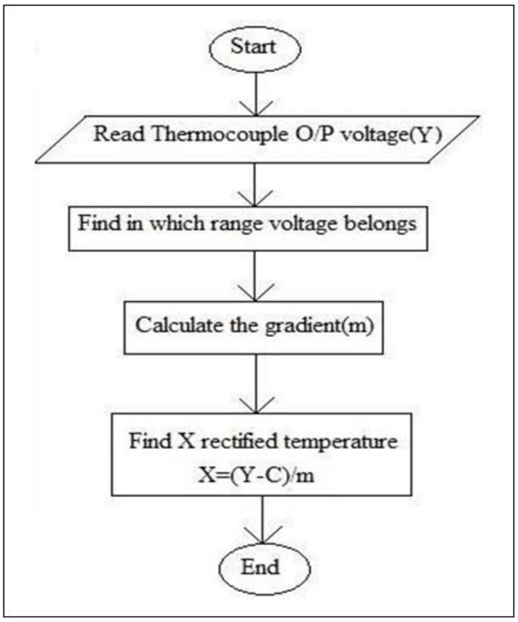
Voltage(mv)	Temp range(°C)
1.537 - 2.059	30 - 40
2.059 - 2.585	40 - 50
2.585 - 3.116	50 - 60
3.116 - 3.650	60 - 70
3.650 - 4.187	70 - 80
4.187 - 4.726	80 - 90
4.726 - 5.269	90 - 100
5.269 - 5.814	100 - 110
5.814 - 6.360	110 - 120
6.360 - 6.909	120 - 130
6.909 - 7.459	130 - 140
7.459 - 8.010	140 - 150
8.010 - 8.562	150 - 160
8.562 - 9.115	160 - 170
9.115 - 9.669	170 - 180
9.669 - 10.224	180 - 190
10.224-10.779	190 - 200
10.779-11.334	200 - 210

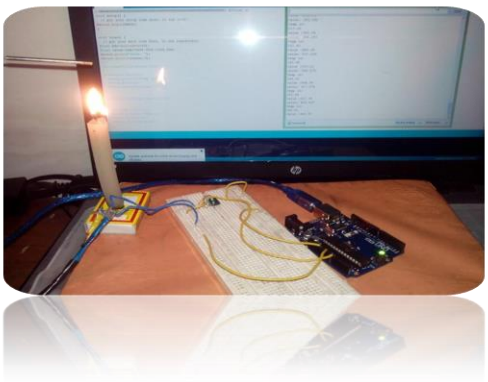


Thermocouple voltage is amplified by a amplifier The output of J Type thermocouple is very small that is impossible to identify by Arduino so it is passed through an Amplifier with a gain (K) then the output voltage is inserted to Arduino. In Arduino after applying code we get the rectified result in serial monitor i.e. nothing but a pc.

Here Room temperature is taken as reference temperature. Room temperature is measured & corresponding voltage for particular thermocouple noted down from reference chart & correction factor is added. Room temperature may be measured using LM 35 sensor connected with Arduino & Correction factor also done directly through coding

III. FLOW CHART





IV. TABLE

1. DATA OF INPUT TEMPERATURE AND OUTPUT VOLTAGE BEFORE OPTIMIZATION

TEMPERATURE(°C)	VOLTAGE(MV)
47.96	2.48
72.74	3.75
117.1	6.10
131.7	6.90
167.0	9.30

2. DATA OF INPUT TEMPERATURE AND OUTPUT VOLTAGE AFTER OPTIMIZATION

TEMPERATURE(°C)	VOLTAGE(MV)
47.96	2.52
72.74	3.91
117.1	6.22
131.7	7.03
167.0	8.98

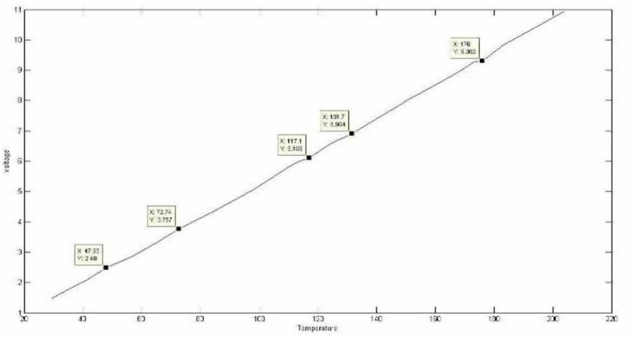
3.DATA OF INPUT TEMPERATURE AND OUTPUT VOLTAGE FROM THERMOCOUPLE REFERENCE TABLE

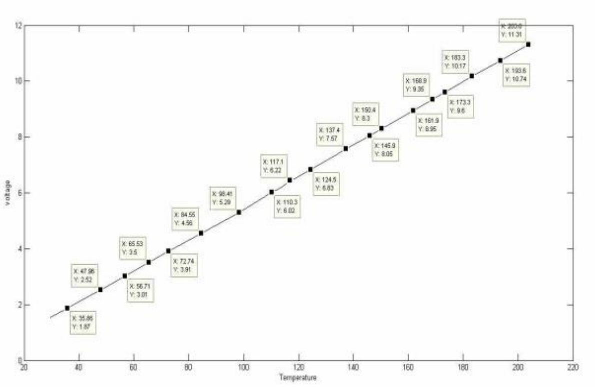
Temperature(°C)	Voltage(mv)
47.96	2.480
72.74	3.864
117.1	6.196
131.7	7.019
167.0	8.949

4.ERROR CALCULATION

Temp(°C)	Voltage(mv)	Voltage(mv)	ERROR%
47.96	2.52	2.480	-4%
72.74	3.91	3.864	-4.6%
117.1	6.22	6.196	-2.4%
131.7	7.03	7.019	-1.1%
167.0	8.98	8.949	-3.1%

V. GRAPHICAL REPRESENTATION





VI. CONCLUSION

The proposed work is a clear significant improvement of thermocouple response. This work optimizes the problem of nonlinearity error of thermocouple response not only for a certain value of temperature but also different values of temperatures using piecewise linear approximation technique . This paper shows how non linearity in the thermocouple response can be reduced significantly by a simple algorithm. The possibility of the technique has been shown by providing experimental results.

VII. ACKNOWLEDGEMENT

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