A New Sensor-based Temperature Measuring System with high accuracy for wide temperature range applications

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Abstract.
A new sensor-based temperature measuring system with high accuracy is presented in this paper. The temperature accuracy smaller then 0.02K is the measured performance of the measuring system after calibration at ten temperatures, over the -50\(^\circ\)C to 300\(^\circ\)C targeted temperature range. Comparing with the traditional temperature measuring system, the advantages of the new sensor-based temperature measuring system are the high precision, immunity to noise, independent with the length of sensor wires and remote operation. And all these are at a low cost with less then 36mW of power consumption. Therefore the sensor-based temperature system is suitable for any field where reliable and accurate temperature measurement or a wide measurement range is necessary.

Introduction
This paper presents the principle of sensor-based temperature measurement, the design, construction and testing of the high accuracy temperature measuring system.

The design of the temperature measuring system based on temperature sensors has a great influence on the system sensitivity. The unbalanced DC bridge based on thermistor with two wires is used in the traditional temperature measuring system, the disadvantage is that that the output voltage of the system is constructed by both of the voltage across the thermistor sensor and the voltage of its wires, and therefore the change of the value of the thermistor sensor will have an effect on the results of system calibration if the length of the wires changed. Besides the system based on unbalanced DC bridge is sensitive to the change of current flows in the ground plane.

Considering this, a 4-wire temperature measuring system based on thermistor sensor is designed in the paper. And the test result shows that the measuring results are independent of the resistor of the thermistor sensor wires, and the temperature accuracy is smaller than 0.02K.

Principle of temperature measurement
The choice of temperature sensor required an exhaustive study of the literature on the subject and of those devices commercially available, since it constitutes one of the key elements to obtain better performance from the measuring system, and due to the precision, scale and cost, the thermistor sensor chosen in the temperature measuring system offer certain advantages such as high accuracy and stability, standard devices in industry, and it has a wide range of temperature measurement between -50 \(^\circ\)C to 300\(^\circ\)C.

The resistance-temperature characteristic of the thermistor sensor is presented in Eq. 1:

\[
\begin{align*}
-50^\circ C &< t < 0^\circ C & R_t = R_0[1 + At + Br^2 + C(t - 100)r^3] \\
0^\circ C &< t < 300^\circ C & R_t = R_0[1 + At + Br^2]
\end{align*}
\]

\[\text{(1)}\]
And here $R_t$ is the value of thermistor when the temperature is $t \degree C$, $R_0$ is the value of thermistor when the temperature is $0 \degree C$, and the coefficient is: $A=3.9083 \times 10^{-3} \degree C^{-1}$, $B=-5.775 \times 10^{-7} \degree C^{-2}$, $C=-4.183 \times 10^{-12} \degree C^{-4}$.

In the 4-wire measuring system, two wires of the thermistor are used to provide the constant current source, and the other two wires are used to measure the own voltage drop of the thermistor. Together with the designed measuring circuit, a high accuracy temperature measuring system is generated. And it would have different applications in a huge variety of fields, both commercial and scientific.

**Design of the temperature measuring system**

The schematic drawing of the temperature measuring system is shown in Fig. 1. $R_1$ is the precision resistance used to generate the constant current source together with the precision operational amplifier and the voltage reference. $R_t$ is the thermistor sensor and the four wires of $R_t$ is $Rx_1$, $Rx_2$, $Rx_3$ and $Rx_4$. $R_g$ is also a precision resistance used to control the gain of the precision instrumentation amplifier.

![Fig. 1 Schematic Drawing of the temperature measuring system](image)

**Power Supply Section.**

The voltage reference is used to provide a precision constant voltage; the operational amplifier takes charge of converting the constant voltage source to the constant current source. And in the four wires of the $R_t$ thermistor sensor, the $Rx_1$ and $Rx_4$ is the dynamic wires, and they are used to connect the thermistor sensor to the constant current source.

**Temperature Measuring System.**

The other two wires $Rx_2$ and $Rx_3$ of the $R_t$ thermistor sensor are the sensor wires, they are used to connect the voltage of the thermistor sensor to the temperature measurement interface. As the input impedance of the precision instrumentation amplifier is high enough, we can take for granted that there is no current flowing on the inputs. Therefore there is no current flowing across the wires of $Rx_2$ and $Rx_3$, and the voltage between the inputs of the instrumentation amplifier is just the voltage of thermistor sensor itself and is not relevant to the resistance of $Rx_1$ and $Rx_4$.

In the temperature measuring system, the instrumentation amplifier is used in substitution for three operational amplifiers; the reason lies in that the specifications for input voltage offset and noise have multiplied by $\sqrt{2}$ in the differential system constructed by three operational amplifiers and in the three operational amplifier type, there are two operational amplifiers at the inputs, and both contributing to the overall input error.

This new type of design has high temperature stability and simple structure, and it could separate the constant current source from the temperature measurement circuit. And the advantage is that even if the voltage drop should happen in the $Rx_1$ and $Rx_4$ wires, the accuracy of the output voltage will not be affected.
Test of the temperature measuring system

Test Method.

Ten temperature reference points are calibrated by placing the temperature measuring system under high and low temperature conditions. Considering the operating temperature range of the related devices, we set the test temperature range as -40 °C to 50 °C and the temperature interval as 10 °C. The data acquisition will begin if the temperature has been keeping more than one hour.

To calibrating the temperature measuring system, we use the output temperature of the LakeShore Temperature Measuring Instrument to fit the output voltage of the 4-wire temperature measuring system, and the fitting results are satisfied, and it is also used to provide the standard temperature for calibration and comparison.

Accuracy Test.

The output voltage and the temperature-voltage curve are shown in fig. 2.

![Fig. 2 the output voltage and the temperature-voltage curve](image)

The linear fitting result of the temperature and the output voltage is $T = 50.76109 \times \text{Volt} - 256.92149$; and the correlation coefficient is more than 0.9999. we can conclude that the output voltage has a good linear relation with standard temperature.

The results of temperature error derived by linear fitting and quadratic fitting are shown in fig. 3.

![Fig. 3 the temperature error by linear fitting and quadratic fitting](image)

The results show that the temperature error is less than 0.02 °C after quadratic fitting, and it could meet the demand of most applications. This new type of temperature measuring system has been registered, for its patent, in the Chinese Intellectual Property Office, with the application number ZL200920109994.5.
Consistency Test among multi-channels.

To validate the consistency among multi-channels, ten separated temperature measuring systems are tested, and the difference value between the actual measurement results of each channel and the average measurement results is shown in Fig. 4.

Fig. 4 the consistency by linear fitting and quadratic fitting among ten channels

We can see from the test results that the consistency among ten separated channels is better than 0.01 °C after quadratic fitting. And therefore the temperature measuring system is suitable for many applications with high requirements to the accuracy and consistency.

Conclusions

A new type temperature measuring system is presented which offers high accuracy, low power consumption and simple structure. It was demonstrated by means of low and high temperature experimentation that the accuracy of the temperature measuring system is less than 0.02 °C, and the consistency among multi-channels is better than 0.01 °C, so it is suitable for a wide range of occasions, such as industrial control, automotive, and space instrument. Besides the output voltage has no relation to the length of the thermistor sensor wires, therefore the temperature measuring system is especially suitable for the fields in which remote control is needed.

References


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