Calibration of Buffer-less system for thermistor temperature measurement

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Abstract. This paper presents a temperature measurement system without the input buffer. A voltage follower or a buffer is required to minimize the influence of the ADC input impedance in the thermistor temperature measurement system. In such system, a high performance operational amplifier is usually required to prevent the noise and distortion due to the additional circuit. Negative power is also necessary to prevent the distortion of the low voltage input signal. This paper introduces a buffer-less system with a calibration method to resolve such problems. The low temperature coefficient precision resistors were employed to calibrate the input resistance and the leakage current of ADC. The experimental results show that the calibrated error decreased from 190mK to 40mK.

Keywords: Thermistor, input impedance, operation amplifier, buffer.

1 Introduction

Among the various temperature measuring devices that has been developed, NTC thermistor has a 10-fold higher temperature coefficient than the commonly used platinum sensor, and shows several advantages such as high sensitivity, fast thermal response, various shapes and sizes, and low-cost [1,2].

When the divided voltage is applied to the ADC, the voltage divider is isolated from the ADC with a voltage follower or a buffer made with an operation amp (OP amp), in order to minimize the influence of the ADC input resistance. However, the additional circuitry and the buffer nonlinearity can cause noise or distortion of the divided voltage signal. Also, a negative voltage source is required for the buffer to prevent the distortion of the low divided voltage input.

If the ADC input impedance is known, the resistance of the thermistor, that is, the temperature can be measured accurately by directly connecting the divided voltage to the ADC without any buffer. In this paper a calibration method is proposed and applied to the temperature measurement system which consists of a simple voltage divider and a microcontroller with ADC. The input impedance of the ADC is modeled and identified with the calibration method. The emulation of thermistor resistance is measured using four precision resistors, and it was determined whether this measured

temperature was time-invariant. Also a calibration method using the input impedance from the measure temperature is proposed.
Experimental results show that the proposed model was a good approximation of the ADC input impedance and the calibrated temperature error was significantly reduced. As a result, it was shown that the ADC input impedance is time-independent.

2 Methods

In this paper, the 8-bit microcontroller (PIC18F4458, microchip technology inc.) with an integrated 12bit ADC was selected as the temperature measurement system. The ADC has 10 input channels and four of them were selected to be connected to the voltage divider. The system was intended to measure the heat blocks of the PCR thermal cycler and the interchangeable thermistor (U.S. Sensor Corp.) having the precision of 0.1°C was selected. As the important temperatures are 4°C, 60°C, 72°C, and 95°C in the system, the precision resistors with similar resistance of the thermistor at the temperatures were employed to emulate the thermistor. The corresponding temperatures of the selected precision resistors were 4.0°C, 60.0°C, 72.3°C, and 95.0°C. The circuit module with the resistors and switches was assembled to apply any of them to any of the voltage divider circuits.

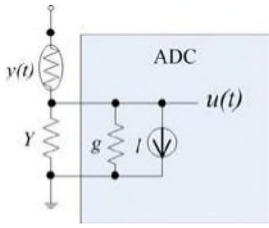

Fig. 1. ADC input impedance model.

Each resistance in figure 1 is represented in admittance for easy derivation of the calibration equations as follows:

$y(t)$: $1 / r(t)$, Y : $1 / R$, g : ADC input admittance , l : ADC input leakage current

According to Kirchhoff's law:

The two unknown parameters can be calibrated with the ADC results by connecting two thermistors. To simplify the unknown parameters, substitute $g_i = Y + g$, and calculate g_i and l . Rearranging equation (2) according to parameter will yield the following.

$$(1-u)y=g_i u+l \tag{3}$$

Put the thermistor admittance as y_1 , y_2 and the ADC result by connecting the two as d_1 , d_2 , for two temperatures t_1 , t_2 . Put the maximum value of ADC as N (for 12 bit, N=4096). Then, two equations can be obtained for the unknown parameters, g_i and l , as the following.

$$y_1 = g_i \left(1 - \frac{d_1}{N}\right)\frac{d_1}{N} + l, \quad y_2 = g_i \left(1 - \frac{d_2}{N}\right)\frac{d_2}{N} + l \tag{4}$$

By calculating g_i and l from the two simultaneous equations in (4), the system can be calibrated. However, it is recommended to calibrate for more than two temperatures since the calibration is done for more than two important temperatures in real thermistor calibration. In this case, there will be more than two equations in the form of equations shown in (4), and will be able to calculate more stable parameters through the least square method. The equations for p , A , and B of above is shown below.

$$p = \begin{bmatrix} g_i \\ l \end{bmatrix}, A = \begin{bmatrix} \left(1 - \frac{d_1}{N}\right)\frac{d_1}{N} & 1 \\ \left(1 - \frac{d_2}{N}\right)\frac{d_2}{N} & 1 \\ \left(1 - \frac{d_3}{N}\right)\frac{d_3}{N} & 1 \\ \left(1 - \frac{d_4}{N}\right)\frac{d_4}{N} & 1 \end{bmatrix}, B = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} \tag{5}$$

Figure 2 shows the diagram of the connection between the thermistor emulation system and the temperature measurement system in order to calibrate the points of four significant temperatures of the thermocycler. Four of the precision resistors that correspond to the thermistor resistance of the four temperatures are attached to the thermistor emulation, which can be connected and disconnected with a switch.

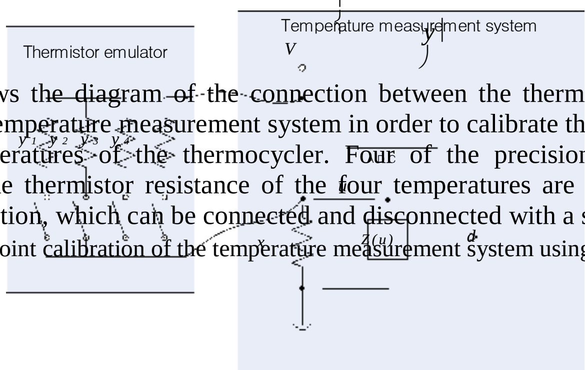

Fig. 2. Four point calibration of the temperature measurement system using thermistor.

To calibrate the admittance into ADC values, the data set $\{(y_1, d_1), (y_2, d_2), (y_3, d_3), (y_4, d_4)\}$ is obtained by connecting the switches, and the unknown parameters are calculated with equation (5).

3 Results and Discussions

The temperature was measured by connecting the precision resistors corresponding to the temperatures of 95.07 72.36°C, 60.05 and 4.02°C as described in the previous section. The temperature coefficient of the precision thermistor is $\pm 25ppm/$□ , and the tolerance is $\pm 0.1\%$. The channel and the set variation of the ADC input impedance are negligible. However, the temperature measurement error was 220, 170, 130, and 250mK in absolute temperature for 95.07°C, 72.36°C, 60.05°C, and 4.02°C, respectively.

Table 1 shows the temperature measurement error after calibration with the suggested method. Comparing the second and the third rows, it is noticeable that the calibrated error is significantly reduced. The error was reduced to one-eighth and the overall error was reduced to less than 30mK, which was acceptable for most applications. The results indicate that an accurate temperature measurement is possible without the isolation of the ADC and voltage divider through a buffer. Such result has great significance considering the noise due to an additional circuit, distortion from the nonlinearity of poor operation amplifier, and the negative power supply.

The variation between the sets and between the channels of the ADC input impedance was negligible in this experiment.

Table 1. Calibration results.

True temperature (°C)	95.07	72.36	60.05	4.02	mean
Error mean (°K)	0.22	0.17	0.13	0.25	0.19
Calibrated error mean (°K)	0.02	0.01	0.04	0.09	0.04

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