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Study of Solar Water Heater Temperature Detection Method

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Abstract: Based on mass production, cost saving and other commercial ideas, the temperature detection module in solar water heaters usually use inexpensive temperature sensors with low sensitivity and accuracy, the design in the hardware conditions are not ideal conditions, in order to make the temperature detection error to meet the design requirements, the design needs temperature detection range of -10 to 100, the temperature detection error range required to control ± 1, now the Multiple temperature detection methods are compared and studied to come up with a temperature detection method with high stability and low error to meet the design requirements. In this paper, the three methods of fitting, interpolation and table look-up method are compared and analyzed under the condition that the hardware accuracy is not high, and MATLAB software is used to conduct simulation experiments to verify whether the error meets the design requirements, and data are collected in reality to verify whether the accuracy meets the error requirements. The experimental results show that the look-up table method is based on the schematic diagram to get the relationship between the ADC sampling value and the temperature value, with the advantage that environmental errors can be ignored, etc., can better meet the requirements of the accuracy of the solar water heater temperature measurement error, and the performance is more stable and reliable.

Keywords: Temperature Detection, Error, Interpolation, Table Look-up Method

1. Introduction

Solar water heaters are widely used in rural areas and other areas, which is conducive to energy saving and environmental protection. In the solar water heater design, the error accuracy of the temperature detection module needs to meet the design requirements. The temperature detection range required in this study is -10°C to 100°C, and the measurement error accuracy is required to be controlled within ±1°C. Considering factors such as mass production and cost saving, the accuracy of the temperature sensor used is not high, and the error between the sampling value collected by the temperature detection module and the actual value in the inner chamber does not meet the design For this reason, a variety of temperature detection methods are compared, and a stable and less error detection method is derived [1-4].

In this paper, the three methods of fitting, interpolation and table look-up are experimentally compared, and the error, stability and other aspects are comprehensively examined, and the experimental results show that the table look-up method can better meet the requirements of temperature measurement accuracy of solar water heaters.

2. Working Principle of Temperature Measuring NTC Temperature Sensor

The temperature detection module in the solar water heater is crucial, for the user, the user must know the real temperature value, based on this temperature value to further set the temperature value and time required to heat to the operation, for the water heater itself, any operation is based on the collection of the temperature value in the tank, if the collected data and the theoretical value of the error is large, it will be executed with the design will If the error between the collected data and the theoretical value is large, it will perform operations contrary to the design, which will seriously affect the life of the machine and the user's personal safety [5-8].

2.1. Working Principle of Temperature Measuring NTC Temperature Sensor

The temperature sensor model used in the design of the water heater is a glass-cased temperature measuring NTC thermistor, which is a thermistor with a negative temperature coefficient characterized by a significant decrease in resistance as the temperature rises. It is manufactured by ceramic process using metal oxides such as manganese, cobalt, nickel, iron, copper and aluminum as the main materials [9].

NTC thermistor resistance value and temperature into a one-to-one relationship, the use of NTC thermistor resistance of this temperature characteristics, the temperature value can be calculated from the measured resistance value, which is the principle of NTC thermistor temperature measurement. In the water heater temperature detection module will measure the temperature sensor connected to the water heater controller, due to temperature changes resistance value along with the change, according to the principle of resistance voltage division can be understood that the voltage value on the corresponding pins of the MCU also changes along with the temperature, that is, the temperature value of the NTC thermistor and the voltage value of the corresponding pins on the MCU is also a one-to-one correspondence, the experiment through the ADC acquisition of the corresponding pin voltage value The corresponding temperature value can be calculated at the same time [10].

2.2. Display Module

The temperature display module uses the TM1640 chip, which is a 2-wire serial common cathode 8-segment 16-bit LED driver control circuit with integrated MCU digital interface, data latch, LED driver and other circuits, featuring excellent performance and reliable quality.

The TM1640 works by sending the address of the digital tube and the segment code that needs the digital tube to display the number of the command way to make the LED display the temperature value, also can send the corresponding command to adjust the brightness of the LED display, suitable for application in the solar water heater temperature display module. The block diagram of the circuit system composition is shown in Figure 1 below [11].

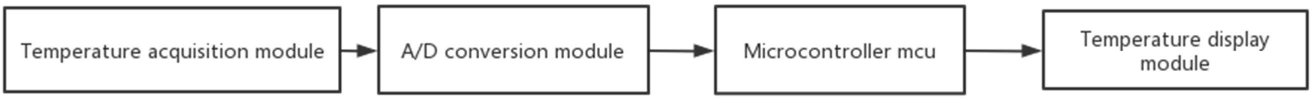

Figure 1. *Block diagram of circuit system composition.*

2.3. Data Acquisition

Take a cup of hot water about 100°C, the thermometer and temperature sensor bundled together submerged in hot water, run the ADC sampling program written on Keil debugging software, observe the thermometer each drop of 1°C will correspond to the ADC sampling value and temperature value recorded, repeat the above steps, get a number of groups of experimental data saved in excel, use the graphical display of the data collected in excel, as shown in Figure 2 below, the vertical coordinate is the ADC sampling value, the horizontal coordinate is the real-time environmental temperature value.

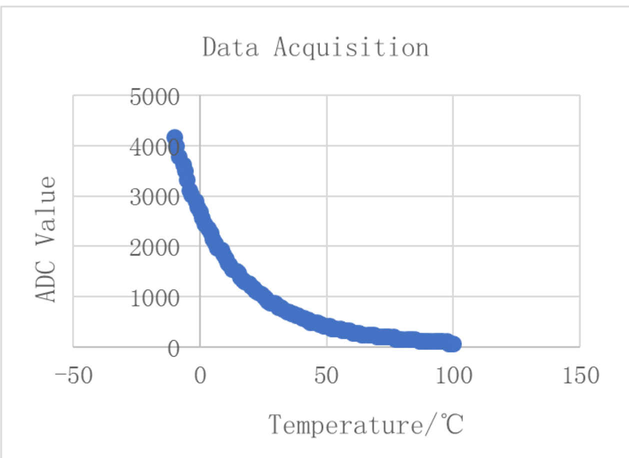

Figure 2. *Data Acquisition.*

3. Algorithm Principle and Experimental Comparison

According to the temperature measurement principle of NTC and Figure 1 can be seen, as the temperature rises ADC sampling value decreases, the two variables show a negative correlation between the characteristics of each temperature value corresponds to an ADC sampling value, if you know the relationship between the two can be determined by the ADC sampling value of the LED corresponding to the temperature value to be displayed. If the relationship between the temperature value and the ADC sampling value can be established through the algorithm, you can react to the temperature value in the water heater by the value of the temperature sensor, that is, the ADC sampling value, when the accuracy requirements are controlled at -1°C ~ 1°C, it is necessary to establish a link between the algorithm error is small, so as to meet the accuracy requirements of the design [12].

3.1. Triple Spline Interpolation

Interpolation is the complementary interpolation of a continuous function on top of the discrete data so that this continuous curve passes through all the given discrete data points. Algorithmically satisfying the design requirements of the water heater, the interpolation algorithm can be used to establish the relationship between the temperature value and the ADC sampling value of the temperature sensor. Assume that the given interval [a,b] is provided with n+1 mutually exclusive interpolation nodes x0<x1<x2<... <xn, the values of the corresponding functions are known as shown in Table 1.

Some of the data collected for the solar water heater are shown in Table 2 below.

Table 1. *x and f(x).*

x	x_0	x_1	x_2	...	x_n
f(x)	y_0	y_1	y_2	...	y_n

Table 2. *Temperature values and ADC sampling values.*

Temperature value	10	11	12	13	14
ADC value	1775	1696	1630	1568	1508
Temperature value	20	21	22	23	24
ADC value	1201	1158	1116	1075	1037
Temperature value	30	31	32	33	34
ADC value	835	805	777	750	724
Temperature value	40	41	42	43	44
ADC value	587	567	548	529	512
Temperature value	50	51	52	53	54
ADC value	417	403	390	377	365

If there is a segmentation function

$$S((x) = \begin{cases} S_1(x), & x \in [x_0, x_1) \\ S_2(x), & x \in [x_1, x_2) \\ \ldots\ldots\ldots & \\ S_n(x), & x \in [x_{n-1}, x_n] \end{cases} \quad (1)$$

Satisfy the conditions.

(1) S(x) is a cubic polynomial on each small interval $[x_n, x_{n+1})$;

(2) S″(x) is continuous on the interval [a,b];

$$S(x_j)=y_j \ (j=0,1,2,\ldots,n). \quad (2)$$

S(x) is said to be the three-sample interpolation function of f(x). s(x) is the three-sample interpolation function of f(x) shall satisfy the following conditions.

(1) Interpolation conditions and functional continuity conditions are 2n.

$$S(x_j)=y_j \ (j=0,1,2,\ldots,n), \quad (3)$$

$$S(x_j+0)=S(x_j-0) \ (j=0,1,2,\ldots,n-1); \quad (4)$$

(2) There are n-1 first-order derivative continuity conditions at all internal nodes.

$$S'(x_j+0)=S'(x_j-0) \ (j=0,1,2,\ldots,n-1); \quad (5)$$

(3) There are n-1 second-order derivative continuity conditions at all internal nodes [6].

$$S''(x_j+0)=S''(x_j-0) \ (j=0,1,2,\ldots,n-1); \quad (6)$$

The relationship between the collected data can be established by using interpolation as follows: the data collected in Figure 2 is imported into matlab, and the results of the three-sample interpolation in matlab using the smoothing spline function (three-sample interpolation function) are shown in Figure 3.

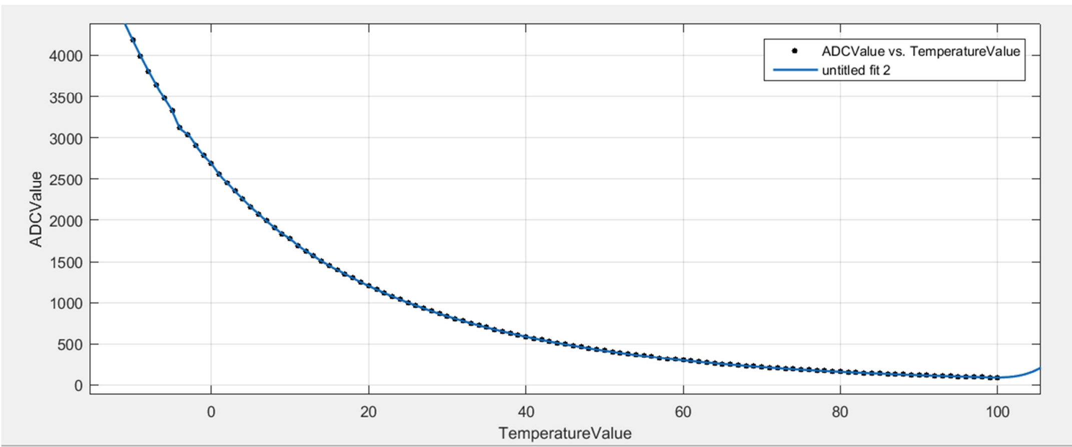

Figure 3. *Triple spline interpolation.*

The graph obtained by interpolation can be obtained from Figure 3 after all the known interpolation points, the graph is smoother and can be approximated as a function of the ADC sampling value and temperature [13].

3.2. Polynomial Fitting Method

If a curve can be found to infinitely approximate the collected data, as long as the error is small it can be seen as a relationship between the temperature value and the temperature sensor ADC sampling value, which is reflected in the algorithm as a fitting algorithm, fitting that is to find a curve to infinitely approximate the given data point.

The linear fit function: Φ(x)=a+bx is determined from the experimental data collected from the data and is called a linear fit to the data. For the linear fit problem, it is necessary to find the minimum point of the function (2). The geometric background of the problem is to seek a line that minimizes the sum of squares of the longitudinal distances of the line from the scattered points of the plane identified by the data table.

$$S(a,b)=\sum_{k=1}^{m}[(a+bx_k)-y_k]^2 \tag{7}$$

From the derivative of the function with respect to the two variables, we get:

$$\frac{\partial S}{\partial a}=2\sum_{k=1}^{m}[(a+bx_k)-y_k] \tag{8}$$

$$\frac{\partial S}{\partial b}=2\sum_{k=1}^{m}[(a+bx_k)-y_k]x_k \tag{9}$$

Letting it equal to zero, we obtain the regular system of equations.

$$\begin{cases} ma+\sum_{k=1}^{m}x_k b=\sum_{k=1}^{m}y_k \\ \sum_{k=1}^{m}x_k a+\sum_{k=1}^{m}x_k^2 b=\sum_{k=1}^{m}x_k y_k \end{cases} \tag{10}$$

Similar to the above derivation, in the polynomial fit problem for the data, In order to determine the fitted function of the coefficients, it is necessary to solve the system of regular equations.

$$\psi(x)=a_0+a_1x+a_2x^2+\dots+a_nx^n \tag{11}$$

$$\begin{bmatrix} m & \sum_{k=1}^{m}x_k & \dots & \sum_{k=1}^{m}x_k^n \\ \sum_{k=1}^{m}x_k & \sum_{k=1}^{m}x_k^2 & \dots & \sum_{k=1}^{m}x_k^{n+1} \\ \dots & \dots & & \dots \\ \sum_{k=1}^{m}x_k^n & \sum_{k=1}^{m}x_k^{n+1} & \dots & \sum_{k=1}^{m}x_k^{2n} \end{bmatrix}\begin{bmatrix} a_0 \\ a_1 \\ \dots \\ a_n \end{bmatrix}=\begin{bmatrix} \sum_{k=1}^{m}y_k \\ \sum_{k=1}^{m}x_k y_k \\ \dots \\ \sum_{k=1}^{m}x_k^n y_k \end{bmatrix} \tag{12}$$

The data collected from the experiments in Figure 2 will be called in matlab software polyfit function (polynomial fit) for polynomial fit results are shown in Figure 4 below, and the polynomial fit out function relation is shown in the upper right corner of Figure 4.

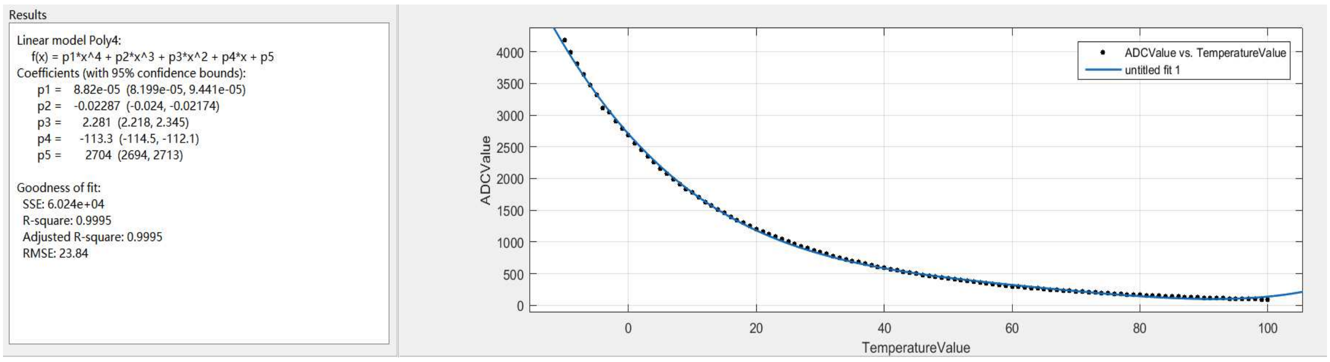

Figure 4. *Polynomial fit.*

The results of the polynomial fitting residuals are shown in Figures 5 below, with periodic errors between 15°C and 90°C, and larger errors below 15°C and above 90°C. Whether the specific errors meet the design requirements needs to continue to be verified.

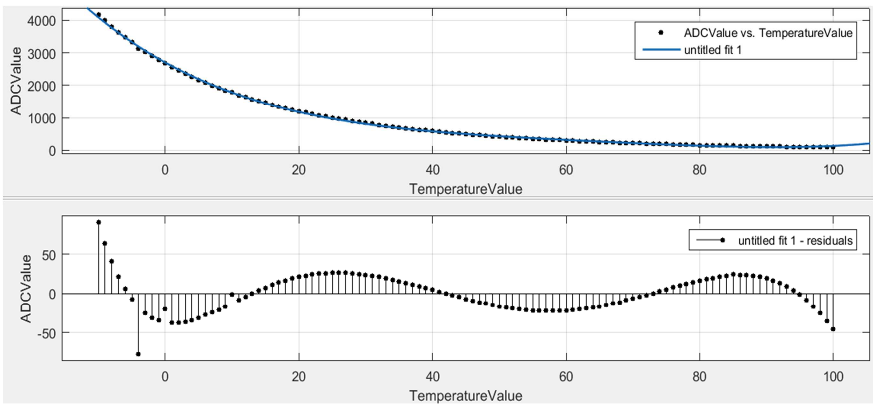

Figure 5. *Polynomial fit with residuals.*

The relationship between the ADC sampling value and the temperature value obtained by fitting the polynomial y=8.82e-05*x^4-0.2287*x^3+2.281*x^2-113.3*x+2704 is added to the temperature detection code, and the theoretical temperature value is monitored using the keil5 debugging tool, which corresponds to the corresponding value in the record thermometer, and the comparison between the two can be known Whether the error meets the design accuracy requirements. Specific part of the experimental data are shown in Table 3 below.

Table 3. *Experimental data.*

ADC value	280	278	270	261	252
Theoretical value	60	61	62	63	64
Actual value	59	60	61	62	63
ADC value	1240	1150	1111	1070	1031
Theoretical value	19	22	24	25	26
Actual value	20	21	22	23	24
ADC value	254.3	246.2	238.4	230.9	223.7
Theoretical value	65	66	67	68	69
Actual value	63	64	65	66	67
ADC value	216.7	209.9	203.4	197.1	191.1
Theoretical value	70	71	72	73	74
Actual value	69	70	71	72	73
ADC value	187.2	181.2	176.1	170.9	165.8
Theoretical value	75	76	77	78	79
Actual value	74	74	75	76	77

From Figure 5, it can be seen that the results obtained by polynomial fitting show periodic errors in the overall effect, with large errors at the endpoints, and from Table 3, it can be seen that the error in the local part exceeds -1°C~1°C, and the error accuracy does not meet the design requirements. Interpolation although after all 110 measurement data interpolation nodes, but the interpolation.

nodes taken more and interpolation curve in some intervals appear jump, the phenomenon is known as the Longue phenomenon, in the experimental performance of the jump phenomenon in about -5°C degrees, interpolation nodes more can only ensure the continuity of each interval curve in the connection point, it is difficult to achieve the smoothness of the entire curve, in the temperature detection module code to achieve more cumbersome This does not meet the requirements of certain engineering technologies.

3.3. Checklist Method to Achieve the Temperature Measurement Function

Interpolation and fitting is based on data acquisition through the NTC temperature measurement principle to try to find out the functional relationship between the ADC sampling value and the temperature value, so as to respond to the corresponding temperature value through the ADC sampling value, but the collected data in Figure 2 may have systematic errors, such as uneven water temperature, temperature sensor insensitivity caused by a faster temperature drop when the water temperature is high, atmospheric temperature and other systematic errors, the reality These environmental factors are almost non-existent in the closed water heater, the look-up method can avoid these environmental factors, the look-up method is based on the schematic diagram through the principle of resistance voltage division to calculate the ADC sampling value corresponding to each temperature.

V_{cc} in the ADC sampling module in this design uses 5V, V_{ref} is the internal reference voltage (reference voltage) of the microcontroller is 2.5V, R_0 resistance value of 30KΩ, Cnt for ADC sampling conversion value, the value of R for the NTC resistance value, can be obtained according to the resistance temperature characteristics table provided by the NTC manufacturer, can be derived from the ADC value corresponding to each temperature value according to the formula (14).

$$V_R = \frac{R}{R+R_0} * V_{cc} = \frac{V_{ref}}{4096} * C_{nt} \tag{13}$$

$$C_{\mathrm{nt}} = \frac{V_{cc}*4096}{V_{ref}} * \frac{R}{R+R_0} \tag{14}$$

According to Equation 2.5, the ADC sampling values corresponding to -10°C to 100°C can be calculated, and according to the characteristics of NTC, these values are arranged in a sequence from large to small, and these values are stored in an array from large to small, and when the ADC sampling value is located between 2 values in the array, the corresponding temperature can be obtained by the location of the data in the array. The calculated array is added to the experimental program, and the temperature value obtained according to the ADC sampling value is monitored against the actual temperature in the thermometer using the variable window. The experiment shows that the method can efficiently achieve temperature detection with a temperature detection error within ±1°C, the results of the experimental data section are shown in Table 4 below, and the detection accuracy meets the design requirements.

Table 4. *Temperature test data by table check method.*

ADC value	Theoretical value	Actual value	Error
90.6	100	100	0
91.6	99	99	0
94.2	98	98	0
96.8	97	97	0
99.6	96	96	0
102.4	95	95	0
105.3	94	94	0
108.4	93	93	0
111.5	92	92	0
114.8	91	91	0
118.1	90	90	0
121.6	89	89	0
125.2	88	88	0
128.9	87	87	0
132.7	86	86	0
138.5	85	85	0
140.9	84	84	0
145.1	83	83	0
149.5	82	82	0
154.1	81	81	0
158.9	80	80	0
163.8	79	79	0

4. Conclusion

After the experimental comparison of interpolation, fitting and table look-up method, we can get that the fitting is close to the data acquisition point in general, the error appears periodically and there is a large error at the end point; the interpolation method is based on data acquisition for data processing, due to more interpolation nodes, there is a small jitter in the local part such as -5°C, the local part is difficult to ensure that all meet the design accuracy requirements; the table look-up method is based on the design schematic The table look-up method is based on the design schematic to calculate the ADC sampling value corresponding to the temperature value, compared to the algorithm processing on the basis of data acquisition error is smaller, can ignore the impact of environmental factors and other errors, after experimental comparison can be more suitable for the temperature acquisition module in the solar water heater, the error to meet the design accuracy requirements.

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