Research on Temperature Calculation Method of Electrical Equipment Based on IR Data Compensation

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Abstract. The real-time monitoring of electrical equipment temperature is a work worthy of in-depth study. In this paper, based on MLX90640 chip, the temperature calculation method of electrical equipment based on IR data compensation is studied, and the necessity of IR compensation is proved by the experimental data results before and after IR compensation. The advantages of this method are proved by the measurement results of MLX90640. The calculation method of electrical equipment temperature in this paper provides a certain guarantee for the safe operation of electrical equipment.

1. Introduction
The safe operation of electrical equipment plays an important role in ensuring the stability of power system and the reliability of power supply [1-3]. When the internal temperature of electrical equipment rises too high, it is likely to cause serious accidents. Therefore, real-time monitoring of electrical equipment temperature is a work worthy of in-depth study.

At present, the traditional methods of electrical equipment temperature measurement include infrared temperature measurement, thermal resistance temperature measurement and optical fiber temperature measurement [4]. According to the measured signal, temperature measurement can be divided into electrical signal-based temperature measurement and optical signal-based temperature measurement. The principle of the traditional infrared thermometer is to convert the optical signal detected by the photo-detector into an electric signal, then amplify the signal processing and convert it to the corresponding temperature [5-7]. The feasibility of infrared imaging technology in fault diagnosis of electrical equipment has been studied in reference [8]. The infrared remote on-line system of electrical equipment over-temperature is studied in reference [9] which has been applied in substations. A temperature measuring device of contact high voltage electrical equipment based on wireless communication is designed in reference [10].
Although many achievements have been made in the calculation of electrical equipment temperature, how to improve the accuracy of temperature prediction of electrical equipment based on infrared data is still a subject worth studying. On this basis, this paper will study the electrical equipment temperature calculation method combine MLX90640 data compensation technology.

This article is organized as follows: Section 2 shows the basic principle of pre-compensation temperature calculation, Section 3 shows Internal registers (IR) compensation, Section 4 shows experimental data analysis, in Section 5 some important conclusions are provided.

2. Pre-compensation Temperature Calculation
The measured electrical equipment temperature must be compensated and corrected in order to make the result more accurate. The temperature of electrical equipment before compensation can be calculated by the following formula:

\[ T_d = \left( \frac{V_{PTAT_{at}}}{1 + K_{PTAT} \cdot \Delta V} \right) \cdot K_{TPTAT} + 25 \]  

(1)

Where \( V_{PTAT_{at}} \) is the voltage value of the electrical signal stored in 0x2431 address. \( V_{PTAT} \), \( K_{PTAT} \), \( K_{TPTAT} \) and \( \Delta V \) can be calculated by the following formula:

\[ V_{PTAT_{at}} = \left( \frac{V_{PTAT}}{V_{PTAT} \cdot \alpha_{PTAT} + V_{BE}} \right) \cdot 2^{18} \]  

(2)

\[ K_{PTAT} = \frac{0x5952 \& 0xFC00}{2^{10}} \]  

(3)

\[ K_{TPTAT} = \frac{0x5952 \& 0x03FF}{0xCC5 - V_{dd25}} \]  

(4)

\[ \Delta V = \frac{0xCCC5 - V_{dd25}}{K_{Vdd}} \]  

(5)

Where 0x5952, 0xFC00, 0x03FF and 0xCC5 represent the hexadecimal value stored in MLX90640, \( V_{BE} \) is the value of the hexadecimal value stored in the 0x0700 address. \( V_{dd25} \), \( K_{Vdd} \) and \( \alpha_{PTAT} \) can be shown as:

\[ V_{dd25} = 0x9D68 \& 0x00FF \]  

(6)

\[ K_{Vdd} = \frac{0x9D68 \& 0xFF00}{2^{8}} \]  

(7)

\[ \alpha_{PTAT} = \frac{0x4210 \& 0xF000}{2^{14}} + 8 \]  

(8)
3. IR Compensation

After the parameters restore the temperature calculation is done using calculation in figure 1.

![IR compensation process diagram]

Fig. 1 IR compensation process

The gain factor $K_{gain}$ can be expressed as:

$$K_{gain} = \frac{GAIN}{RAM[0x0704]}$$  \hspace{1cm} (9)

Where $GAIN$ is hexadecimal value stored in 0x2430 address. Gain compensation degree can be shown as:

$$pix_{gain}(12,16) = RAM[0x056F] \times K_{gain}$$  \hspace{1cm} (10)

Another compensation parameter $pix_{OSetf}(12,16)$ can be calculated by the following formula:

$$pix_{OSetf}(12,16) = Off_{seta} + OCC_{row12} \times 2^{OCC_{row}}$$
$$+ occ_{c16} \times 2^{OCC_c} + offset(12,16) \times 2^{OCC_r}$$  \hspace{1cm} (11)

Where $Off_{seta}$ is hexadecimal value stored in 0x2411 address. $OCC_{row12}$ Can be calculated from the numerical value in the 0x2414 address. $OCC_{row}$ And $OCC_c$ can be calculated from the numerical value in the 0x2410 address. $OCC_c$ Can be calculated from the numerical value in the 0x2410 address. $offset(12,16)$ Can be calculated from the numerical value in the 0x25AF address.

$pix_{C}(12,16)$ Can be calculated as:
\[ pixQ(12,16) = pix_{\text{gain}}(12,16) - \]
\[ pix_{\text{OSref}} \ast (1 + K_{Ta} \ast (T_a - T_{a0})) \ast (1 + K_v \ast (V_{dd} - V_{dd0})) \]  

(12)

Where \( K_{Ta} \) can be calculated by hexadecimal values stored in 0x25AF address, 0x2437 address, and 0x2438 address. \( V_{dd0} \) is reference value.

In order to facilitate the calculation of the correction of the gain coefficient of the compensated pixel, \( pix_{\text{OS}}(12,16) \) can be shown as:

\[ pix_{\text{OS}}(12,16) = pix_{\text{gain}}(12,16) - \]
\[ pix_{\text{OSref}} \ast (1 + K_{Ta} \ast (T_a - T_{a0})) \ast (1 + K_v \ast (V_{dd} - V_{dd0})) \]  

(13)

Where \( V_{dd0} \) is reference value

Pixel compensation correction result \( K_{TaCP} \) is:

\[ K_{TaCP} = \frac{K_{Ta,CPEE}}{2K_{Tscael}} \]  

(14)

Where \( K_{Ta,CPEE} \) can be calculated by hexadecimal values stored in 0x243B address. \( K_{Tscael} \) can be calculated by hexadecimal values stored in 0x2438 address.

In addition, the gradient compensation of chess pattern mode and TV interleave mode are used to reduce the influence of adjacent pixels on the pixel, the chess pattern mode is shown as figure 2, the TV interleave mode is shown as figure 3.

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**Fig. 2** Chess pattern mode

**Fig. 3** TV interleave mode
The purpose of the sensitivity normalization is to facilitate compensation calculations where the sensitivity is calculated by the 0x2439 address, 0x2420 address, 0x243C address, 0x2421 address, 0x242B address, 0x2424 address, and 0x258F address. $T_{ij}(12,16)$ can be calculated as:

$$T_{ij}(12,16) = \frac{V_{IR}(12,16)}{\alpha_{comp}(12,16) * (1 - K_{xTo2} * 273.15) + S_{x(12,16)}} + T_{u-r}$$

$$= T_{ij}(12,16) + 273.15$$

(15)

Where $\alpha_{comp}(12,16)$ is sensitivity, $V_{IR}(12,16)$ is voltage after compensation based on gradient compensation. $T_{u-r}$ is the parameter calculated by $T_u$. $K_{xTo2}$ is calculated by 0x243D address and 0x243F address. $S_{x(12,16)}$ is calculated by $K_{xTo2}$, $\alpha_{comp}(12,16)$ and $V_{IR}(12,16)$.

4. Experimental Data Analysis

Comparison between the actual temperature of extracting 6 pixels and the temperature before and after IR compensation and IR compensation, the result can be shown as figure 4. The temperature results compensated by IR are obviously closer to the actual value.

![Fig. 4 Temperature results of pre-compensation and IR compensation](image)

Through the above analysis, it can be seen that the measurement results can be more accurate after IR compensation, so that the temperature of electrical equipment can be accurately understood.

5. Conclusion

The temperature calculation method of electrical equipment based on IR data compensation is studied based on MLX90640, and the effectiveness of the calculation method is proved by experimental data. The results show that IR compensation can make the temperature of electrical equipment more accurate.

Acknowledgments

This work was supported by State Grid Xinjiang Changji Power supply Co., Ltd. Corporation's Science and Technology Project (No.SGXJCJOYYJS1900331).
References

[1] Zhao S, Pan L, Li B. The Study of Transformer Fault Acoustic Signal Processing Based on HHT and Wavelet Contour [C]// Wri Global Congress on Intelligent Systems. 2009.

[2] LI Guoxing, JIANG Ziqiu, WANG Xiaodan. Application of content of SF6 decomposition products in fault diagnosis of SF6 electrical equipment [J]. High-voltage electrical apparatus, 2011, 47(12): 104-108.

[3] Yu-Xiu B I, Bian C. Research on Electric Equipment Fault Diagnose Applied on SF_6's Decomposing Gases [J]. Jiangsu Electrical Engineering, 2007, 26(5): 14-17.

[4] Lin L, Wu D, Zhang X. A substation infrared temperature monitoring and warning system with object separation and image registration [C]// International Conference on Image Processing & Pattern Recognition in Industrial Engineering. 2010.

[5] Huda A S N, Taib S. Application of infrared thermography for predictive/preventive maintenance of thermal defect in electrical equipment [J]. Applied Thermal Engineering, 2013, 61(2):220-227.

[6] Sun T, Jing L, Wang L. Research on detecting defects of square-edged timber of fir and ribbed birch by infrared thermal imager: A study on nondestructive testing of wood defects by infrared thermal imager [C]// International Conference on Biobase Material Science & Engineering. 2013.

[7] Sun Y, Wang Y, Peng S B, et al. Comparison of Infrared Thermal Imager with Infrared Thermometer in Diagnosis of Failure of Electrical Equipment [J]. Infrared, 2015, 137(4):28-33.

[8] Li B S, Xu X T, Cui K B, et al. Application of Infrared Imaging Technology in Fault Diagnosis of Electrical Equipment [J]. Zhejiang Electric Power, 2014, 401-403:974-977.

[9] Song X, Fan S, Bing Y. Implementation of infrared measuring temperature on remote image monitoring and control system in transformer substation [C]// International Conference on Image Analysis & Signal Processing. 2013.

[10] Zhao Y. Monitor and Control System Design of Grain Depot Temperature Based on Wireless Communication Technology [C]// First International Workshop on Education Technology & Computer Science. 2009.