

# Influence of Dust on Temperature Measurement Using Infrared Thermal Imager

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**Abstract**—Temperature measurement by infrared thermal imager is an attractive technique in many fields, and it is of great importance to ensure the measurement accuracy of the infrared thermal imager. Aiming at the influence of dust on the temperature measurement of infrared thermal imager, this paper summarized the dust influence into three categories: dust on the surface of the measured object, dust on the infrared thermal imager's lens and dust in the optical path between the measured object and the infrared thermal imager, and conducted three dust experiments. To quantify the measurement errors caused by dust, the infrared thermal image features that are affected by dust are extracted and a compensation model is established based on polynomial regression. The results indicate that dust can introduce measurement errors of infrared thermal imager and the proposed compensation method can compensate for the measurement errors caused by dust and improve the accuracy of infrared thermal imager.

**Index Terms**—Compensation; dust; infrared thermography; temperature measurement.

## I. INTRODUCTION

ANY object whose surface temperature is higher than absolute zero will radiate infrared energy, and there is a functional relationship between the infrared radiation and the surface temperature of the object [1]. Based on this principle, infrared thermal imagers are designed and developed for temperature measurement for many years [2]. Due to the outstanding advantages of infrared thermal imager, such as non-contact, non-invasive, safe and harmless and providing visible two dimensional thermal images [3], [4], infrared thermal imagers are widely used in temperature detection of power electronics, manufacturing, medical and other processes [5]–[7].

When infrared thermal imagers are applied for temperature measurement, whether the temperature measurement accuracy can meet the demand is one of the most concerned issues. However, the measurement accuracy of infrared thermal imager can be affected by several factors, such as the field of view

of infrared thermal imager [8], the atmospheric transmittance [9], non-uniform response of the probe [10], the measurement distance [11], the ambient temperature and other environmental factors [12], and these factors also limit the application of infrared thermography in many processes.

During the past decades, scholars at home and abroad have studied different factors that influence the infrared temperature measurement and proposed different mathematical modeling methods to analyze and quantify the influence of these factors, enabling us reach a relatively satisfactory temperature measurement performance using infrared thermal imagers [13]–[16]. However, the dust, which is a common environmental factor in many industrial processes, has been neglected and has a non-negligible influence on infrared temperature measurement. In sintering process, rotary kilns are often used to dry and bake pellets, and the dust generated in the rotary kiln is randomly distributed in the optical path, or on the sintered material, or deposited on the lens of the infrared visual temperature measurement system, resulting in non-negligible measurement errors in the detection result of the infrared system [17]. During the burning process of cement clinker, the burning temperature measurement in rotary kiln is also easily affected by dust and smoke [18]. In the process of blast furnace ironmaking, dust is generated randomly near the taphole in the cast field, which have a significant influence on the temperature measurement of molten iron [19]. As far as the authors know, there have been little reports of compensation methods for dust interference when infrared thermal imagers are used for temperature measurement. In [20], the influence of dust in optical path and corresponding compensation method are researched, but the compensation performance is limited due to the calculation error of dust transmittance.

According to the position of dust interference, this paper systematically concludes the interference of dust into three categories: dust on the surface of the object to be measured, dust on the infrared thermal imager's lens and dust in the optical path between the infrared thermal imager and the object to be measured, as shown in Fig. 1. In order to explore the influence of dust on infrared temperature measurement and extend the application of infrared thermal imager in industrial temperature measurement process, this paper mainly aims to conduct temperature measurement experiments under the influence of dust using infrared thermal imager and analyze the influence of dust on infrared temperature measurement. When the infrared temperature measurement is affected by dust, the infrared image features are extracted to quantify the impact of dust. With these features, a nonlinear polynomial

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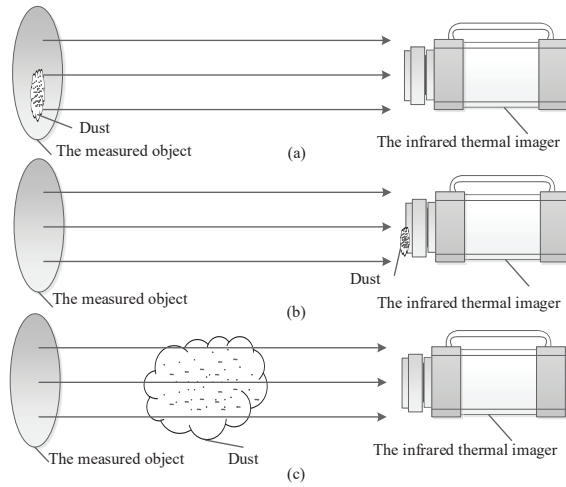


Fig. 1. Different positions of dust interference. (a) Dust on the surface of the measured object. (b) Dust on the lens. (c) Dust in the optical path.

regression model is established to estimate and compensate for the measurement errors caused by dust.

The main contribution of this paper consists of two points: a) The dust influence is comprehensively summarized into three scenarios, and a compensation method is proposed to decrease the dust interference and improve the accuracy of infrared temperature measurement. It is the first time that the influence of dust on infrared temperature measurement is comprehensively researched. b) For the dust influence on infrared temperature measurement in different scenarios, the infrared image features are extracted to analyze the infrared measurement errors caused by dust from the perspective of infrared thermal images, and the polynomial regression-based compensation model is proposed to establish the relationship between the measurement errors caused by dust and the infrared image features and directly compensate for the infrared measurement errors.

## II. DUST EXPERIMENT

To analyze the influence of dust on the temperature measurement results of infrared thermal imagers, this paper has carried out three sets of experiments according to different positions of dust interference: 1) experiments of dust on the surface of the measured object; 2) experiments of dust on the infrared thermal imager's lens; 3) experiments of dust in the optical path. The details are as follows.

### A. Procedure of Experiment

The influence of dust on infrared temperature measurement is the focus of this paper, thus, it is important to ensure that dust is the only variable and that other factors remain unchanged during experiments. Considering the influence of angle of view on infrared temperature measurement, the lens of infrared thermal imager is facing the target surface of blackbody. In order to make the influence of measurement distance on infrared temperature measurement negligible, the distance between the infrared thermal imager and the blackbody is set to 0.53m, which is within the calibration distance.

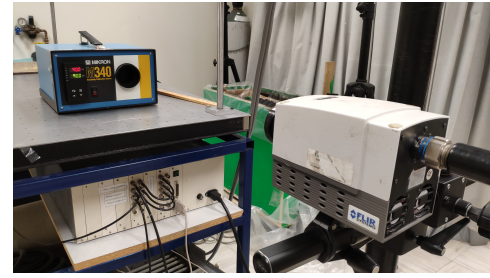


Fig. 2. Picture of dust experiment.

TABLE I  
CHARACTERISTIC PARAMETERS OF DEVICES USED IN EXPERIMENTS

Device	Characteristic parameters	
Infrared thermal imager	Manufacturer and type	Flir X6900sc
	Measurement range	-20°C - 350°C
	Measurement accuracy	±1°C
	Pixel resolution	640×512
Blackbody furnace	Manufacturer and type	MIKRON M340
	Measurement range	-20°C - 150°C
	Emissivity	0.999
	Stability	1 °C
Dust	Source	Cast field of blast furnace

Furthermore, to avoid the influence of ambient temperature and humidity changes on infrared temperature measurement, the dust experiments are carried out in a closed laboratory with constant temperature and humidity, and the hygrothermograph showed that the laboratory temperature is about 23°C and the humidity is 25%.

1) *Dust on The Surface of The Measured Object*: When the experiment of dust on the surface of the measured object is conducted, the blackbody is used as the measured object and the dust from the blast furnace cast field is used to cover part of the target surface of the blackbody, so that infrared temperature measurement results are affected by dust. Fig. 2 shows the dust experiment, and the characteristic parameters of these devices used in this experiment are listed in Table I. The experimental steps are as follows.

Step1: Set the initial temperature of blackbody furnace to 40°C;

Step2: Use the infrared thermal imager detect the target surface of blackbody furnace and record the temperature measurement result when there is no dust on the target surface of blackbody furnace;

Step3: Use dust to cover part of the target surface, save the infrared thermal image of the blackbody furnace, and record the result of infrared thermal imager;

Step4: Denote the temperature difference between the temperature measurement result when there is no dust on the target surface and the result when there is dust on the target surface as  $\Delta T_1$ , and  $\Delta T_1$  is used to indicate the measurement error of infrared thermal imager caused by dust;

Step5: Increase the set temperature of blackbody furnace in a step of 2°C, when the temperature of blackbody furnace is stable, repeat Steps 2, Step 3 and Step 4 until the blackbody furnace's temperature is set to 100°C.



Fig. 3. Experiment of dust in optical path.

TABLE II  
CHARACTERISTIC PARAMETERS OF DEVICES USED IN EXPERIMENTS

Device	Characteristic parameters	
Infrared thermal imager	Manufacturer and type	FLUKE TiX1000
	Measurement range	-40°C - 2000°C
	Measurement accuracy	±1.5°C
	Pixel resolution	1024×768
Blackbody furnace	Manufacturer and type	LUMASENSE M315X8HT
	Measurement range	5°C - 600°C
	Emissivity	1.0
	Stability	0.01 °C
Dust	Source	Cast field of blast furnace

2) *Dust on The Infrared Thermal Imager's Lens*: When the experiment of dust on the infrared thermal imager's lens is carried out, the dust from blast furnace cast field is used to contaminate part of the lens, so that the infrared temperature measurement will be influenced by dust. The devices used in this experiment are the same as these used in the experiment of dust on the surface of the measured object. According to the following steps to conduct this experiment.

Step1: Set the initial temperature of blackbody furnace to 40°C;

Step2: Use the infrared thermal imager detect the target surface of blackbody furnace and record the temperature measurement result when there is no dust on the lens of infrared thermal imager;

Step3: Use dust to contaminate parts of the lens, capture the infrared thermal image of the blackbody furnace, and record the result of infrared thermal imager;

Step4: Denote the temperature difference between the temperature measurement result when there is no dust on the lens and the result when there is dust on the lens as  $\Delta T_1$ ,  $\Delta T_2$  indicates the measurement error of infrared thermal imager caused by dust;

Step5: Increase the set temperature of blackbody furnace in a step of 2°C, when the temperature of blackbody furnace is stable, repeat Steps 2, Step 3 and Step 4 until the blackbody furnace's temperature is set to 100°C.

3) *Dust in The Optical Path*: When the experiment of dust in the optical path between the blackbody and the infrared

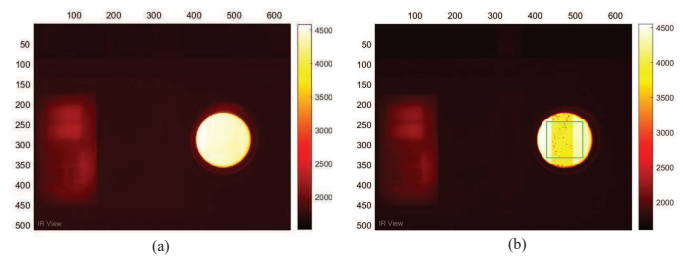


Fig. 4. Infrared thermal image. (a) Without the dust influence. (b) Dust on the surface of measured object.

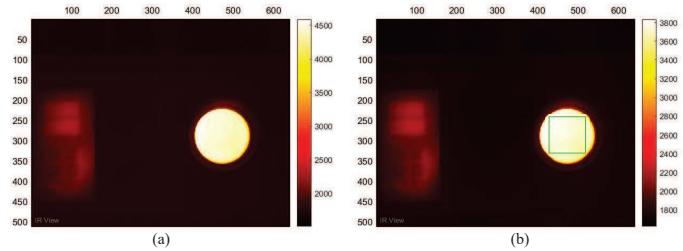


Fig. 5. Infrared thermal image. (a) Without the dust influence. (b) Dust on the infrared thermal imager's lens.

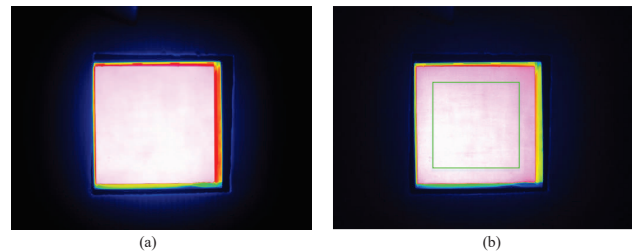


Fig. 6. Infrared thermal image. (a) Without the dust influence. (b) Dust in the optical path.

thermal imager is conducted, a dust area is formed by using a blower and an experimental box, so that the temperature measurement results are influenced by dust when using infrared thermal imager. The experiment box is designed as shown in Fig. 3. The two sides of the experiment box near the blackbody furnace and infrared thermal imager has windows with appropriate size to ensure infrared radiation from the blackbody furnace can be received by the infrared thermal imager. To verify whether the experimental box in the optical path has an effect on the temperature measurement result of the infrared camera, we analyzed the temperature measurement results in two scenarios: placing the experimental box in the optical path and removing the experimental box. The test results show that the experimental box in the optical path almost has no impact on the infrared temperature measurement results. Thus, the experimental box can be used in dust experiment to avoid dust flying. To ensure that the infrared temperature measurement will be affected by the dust in the optical path, we use different blackbody and infrared thermal imager. The parameters of devices used in this experiment are listed in Table II. The experimental steps are as follows.

Step1: Set the initial temperature of blackbody furnace to

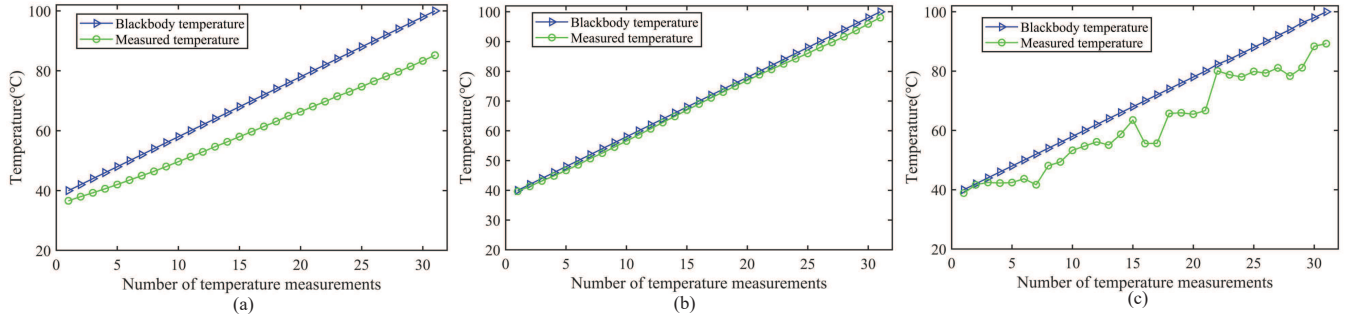


Fig. 7. Temperature measurement results under the dust influence. (a) Dust on the surface of measured object. (b) Dust on the infrared thermal imager's lens. (c) Dust in the optical path.

40°C;

Step2: Use the infrared thermal imager measure the temperature of blackbody furnace and record the measurement result when there is no dust in the optical path;

Step3: Use the blower to generate dust in the optical path between the infrared thermal imager and the blackbody furnace, and the measurement result of infrared thermal imager is recorded simultaneously;

Step4: Denote the temperature difference between the infrared temperature measurement result when there is no dust and the measurement result when there is dust as  $\Delta T_3$ , and  $\Delta T_3$  is used to indicate the measurement error of the infrared thermal imager caused by the dust;

Step5: Adjust the set temperature of the blackbody furnace in steps of 2°C, after the temperature of blackbody furnace is stable, repeat Steps 2, Step 3 and Step 4 until the blackbody furnace's temperature is set to 100°C.

### B. Results of Experiment

Fig. 4~6 show the captured infrared thermal images under three situations of dust interference. From Fig. 4, it can be easily seen that the temperature of the area covered by the dust is significantly lower than the temperature of the area not affected by the dust. As can be seen in Fig. 5, since the lens is contaminated by dust, the temperature of part of the blackbody target surface becomes lower. In Fig. 6, the temperature at the top right of (b) is lower than the temperature at the top right of (a) because of the dust generated by the blower. To simplify the calculation, the rectangles marked in green are used to calculate the measurement results of infrared thermal imager.

Furthermore, to demonstrate the dust influence clearly, the temperature measurement results of the three dust experiments are shown in Fig. 7. When there is dust on the surface of measured object, on the infrared thermal imager's lens, or in the optical path, it is obvious that there are temperature differences between the set temperatures of blackbody and the measurement results of infrared imager. Thus, dust has a significant influence on the infrared temperature measurement and introduces measurement errors in all three situations of dust interference. It should be pointed that the average value in the green rectangle of the infrared thermal image corresponding to the blackbody furnace's target surface is used

as the temperature measurement result of the infrared thermal imager.

## III. COMPENSATION METHOD

The captured infrared thermal images would be affected by the dust when there is dust interference. As a result, the temperature distribution in infrared thermal images would change due to the dust influence. Therefore, we naturally consider the use of infrared thermal image features to quantify and compensate for the measurement errors caused by dust.

### A. Feature Extraction of Infrared Thermal Image

Statistical features characterize the two-dimensional temperature data in the infrared thermal image. Statistical features include the mean value, the standard deviation, the skewness and the kurtosis.

The mean value represents the average temperature level of the whole infrared thermal image. When the infrared temperature measurement is affected by dust, the mean value will change with the temperature distribution in the infrared thermal images.

$$\bar{T} = \frac{1}{n} \sum_{i=1}^n T_i \quad (1)$$

where  $\bar{T}$  and  $T_i$  denote the mean value and the temperature point in the infrared thermal image, respectively.

The standard deviation describes the degree of dispersion among temperature values in two-dimensional temperature data. When there is dust interference, the standard deviation is also influenced by dust.

$$\sigma = \left[ \frac{1}{n} \sum_{i=1}^n (T_i - \bar{T})^2 \right]^{1/2} \quad (2)$$

The skewness refers to the skew state of the asymmetric distribution, which is a measure of the symmetry of the temperature data distribution [21]. When the infrared thermal imager is affected by dust, the temperature data in the infrared thermal imager will change, which affects the skewness.

$$S_k = \frac{1}{n \cdot \sigma^3} \sum_{i=1}^n (T_i - \bar{T})^3 \quad (3)$$

The kurtosis is a feature that characterizes the peak height of the probability density distribution curve at the mean and reflects the sharpness of the peak of the data distribution [21]. The kurtosis under the influence of dust is different from the kurtosis value that is not affected by dust.

$$K = \frac{1}{n \cdot \sigma^4} \sum_{i=1}^n (T_i - \bar{T})^4 \quad (4)$$

### B. Compensation Model

According to the dust experiments, the temperature differences between the blackbody temperature and the measured temperature under dust influence could be considered as the measurement errors of infrared thermal imager caused by dust. To establish the relationship between the measurement errors and the extracted infrared image features, nonlinear polynomial regression is introduced, and the calculation formula for predicting the measurement error is shown as below:

$$\Delta T = \sum_{i=1}^n (a_i x_1^i + b_i x_2^i + c_i x_3^i + d_i x_4^i) + b_0 \quad (5)$$

where  $\Delta T$  represents the temperature measurement error caused by dust,  $x_1, x_2, x_3, x_4$  denote the mean value, the standard deviation, the skewness and the kurtosis of infrared thermal image,  $a, b, c, d$  are constants, and  $n$  denotes the order of the polynomial.

The measurement results and the corresponding image features of dust experiments are used to construct the dataset and to determine the parameters in (5). The extracted infrared thermal image features are used as the inputs of the regression model and the measurement errors are the desired results of the regression model.

For the dataset constructed from the experiment of dust on the surface of the measured object, we gradually increased the order of the inputs until the 6th order, and found that the improvement of R-square (coefficient of determination) is not significant from the first order. Thus, linear regression is adopted to quantify the measurement errors caused by the dust on the surface of the measured object. The specific formulas for the measurement error calculation, in which R-square was 0.993, is shown in (6).

$$\Delta T_1 = 0.2421 \cdot x_1 + 0.1439 \cdot x_2 - 50.0101 \cdot x_3 - 87.2195 \cdot x_4 + 104.446 \quad (6)$$

For the situation of dust on the lens of infrared thermal imager, the similar procedure is utilized to determine the parameters in the regression model, and the specific formula is a multiple binomial, in which R-square was 0.945, as shown in (7).

$$\Delta T_2 = -0.5215 \cdot x_1 + 0.0036 \cdot x_1^2 + 19.1711 \cdot x_2 - 12.4376 \cdot x_2^2 + 54.676 \cdot x_3 + 53.3542 \cdot x_3^2 + 279.0392 \cdot x_4 - 56.407 \cdot x_4^2 - 318.4955 \quad (7)$$

For the situation of dust in the optical path, the procedure for determining the parameters in the regression model is the same

as the aforementioned procedure, and the specific formula, in which R-square was 0.781, is shown in (8).

$$\begin{aligned} \Delta T_3 = & 6.4792 \cdot x_1 - 0.1031 \cdot x_1^2 + 0.0005 \cdot x_1^3 \\ & + 15.8075 \cdot x_2 - 1.1467 \cdot x_2^2 - 2.159 \cdot x_2^3 \\ & + 3.3358 \cdot x_3 + 10.9424 \cdot x_3^2 + 19.4259 \cdot x_3^3 \\ & + 17.8972 \cdot x_4 - 6.468 \cdot x_4^2 + 0.9728 \cdot x_4^3 - 148.456 \end{aligned} \quad (8)$$

When the predicted measurement error  $\Delta T$  is obtained, the compensated result can be expressed as follows.

$$T_c = T_a + \Delta T \quad (9)$$

where  $T_a$  and  $T_c$  denote the measured temperature before and after compensation under the influence of dust, respectively.

## IV. RESULTS AND DISCUSSION

### A. Compensation Results

In order to verify the correctness of the compensation model, the temperature measurement results of infrared thermal imager before and after compensation are shown in Fig. 8. From Fig. 8, we know that in all three scenarios of dust influence, there are certain measurement errors between the measured temperature and the temperature of blackbody before compensation, and the measurement errors are more obvious with the increase of blackbody's temperature. Thus, the measurement errors cannot be ignored. After compensation, the measurement results of infrared thermal imager are close to the real temperature of the blackbody, which demonstrates that the accuracy of infrared thermal imager could be improved by using the proposed compensation method.

Fig. 9 shows the temperature measurement errors before and after compensation in all three scenarios. It can be seen that compared to the measurement errors before compensation, the measurement errors after compensation is significantly reduced, indicating the effectiveness of the proposed compensation method. It should be pointed that from the results of the compensation, the measurement errors caused by dust cannot be reduced completely.

Furthermore, two indicators, which include mean average error (MAE) and root mean square error (RMSE), are introduced to quantify the compensation performance. Table III, Table IV and Table V list the calculated indicators before and after compensation in the three situations of dust interference.

$$MAE = \frac{1}{n} \sum_{i=1}^n |T_i - T'_i| \quad (10)$$

$$RMSE = \left[ \frac{1}{n} \sum_{i=1}^n (T_i - T'_i)^2 \right]^{1/2} \quad (11)$$

where  $n$  denotes the number of times of compensation,  $T_i$  and  $T'_i$  denote the set temperature of blackbody and the measured temperature, respectively.

As can be seen from Table III, the MAE and RMSE are significantly reduced after compensation. When the dust is on the surface of the measured object, the MAE and RMSE are 0.23 and 0.27 after compensation, respectively. The MAE after compensation is improved by approximately 43.57 times compared to the value before compensation, and the RMSE



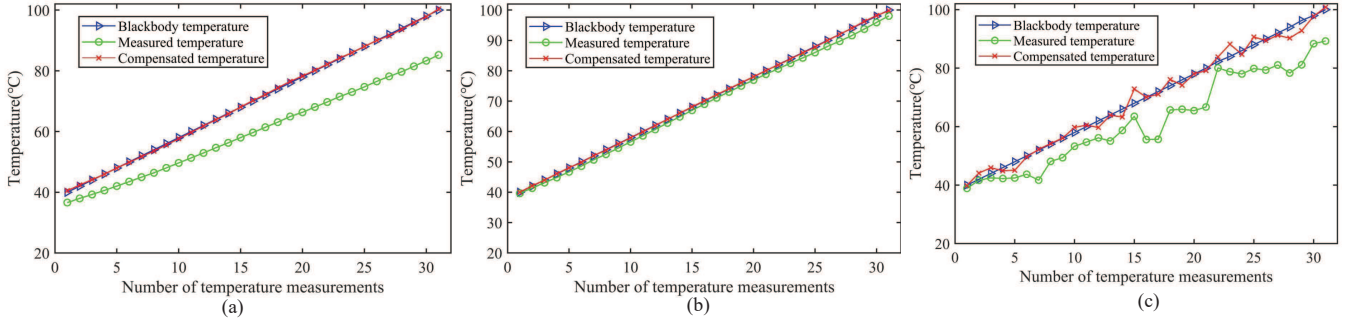


Fig. 8. Infrared temperature measurement results before and after compensation. (a) Dust on the surface of the measured object. (b) Dust on the lens. (c) Dust in the optical path.

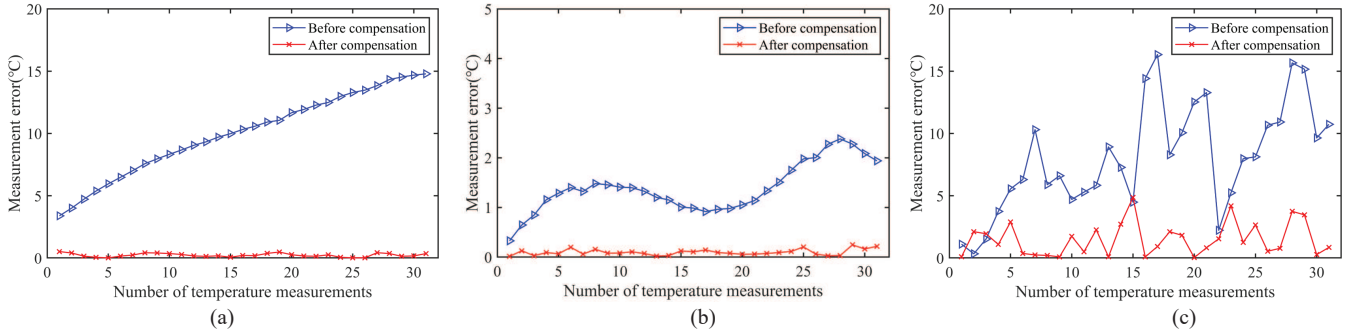


Fig. 9. Measurement errors before and after compensation. (a) Dust on the surface of the measured object. (b) Dust on the lens. (c) Dust in the optical path.

TABLE III

INDICATORS OF DUST ON THE SURFACE OF THE MEASURED OBJECT

Indicator	After compensation	Before compensation	Improvement
MAE	0.23	10.02	43.57
RMSE	0.27	10.55	39.07

TABLE IV

INDICATORS OF DUST ON THE INFRARED THERMAL IMAGER'S LENS

Indicator	After compensation	Before compensation	Improvement
MAE	0.10	1.39	13.90
RMSE	0.11	1.47	13.36

TABLE V

INDICATORS OF DUST IN THE OPTICAL PATH

Indicator	After compensation	Before compensation	Improvement
MAE	1.50	8.04	5.36
RMSE	1.99	9.10	4.57

after compensation is decreased by about 39.07 times. From Table IV and Table V, we also know that the MAE and RMSE after compensation are obviously decreased compared to that before compensation. When there is dust on the lens of infrared thermal imager, the MAE has improved 13.90 times and the RMSE has been reduced by 13.36 times. When there is dust in the optical path, the MAE has improved 5.36 times and the RMSE has been reduced by 4.57 times.

In addition, comparing the compensation performance under

the dust interference at three different positions, the compensation performance of dust in the optical path is not as good as that of the other two positions, which illustrates from the side that the influence of dust in the optical path on infrared temperature measurement is more complicated due to the dynamic distribution of dust in the optical path between the infrared thermal imager and the measured object.

In a word, the proposed compensation method can decrease the dust influence on infrared temperature measurement and improve the measurement accuracy of infrared thermal imager to some extent.

## B. Discussion

From the reduction of infrared temperature measurement error before and after compensation, it is known that by extracting the features of infrared thermal image and constructing the error compensation model, the temperature measurement error caused by dust can be compensated to some extent, and the temperature measurement accuracy of infrared thermal imager is improved. This paper provides a new idea to comprehensively address the impact of dust on infrared temperature measurement and it is possible that the infrared image feature extraction and compensation model can be applied and extended to some infrared temperature measurement processes under the influence of dust, for example, the temperature measurement of cement clinker and sinter in rotary kilns.

It is worth noting that the research about infrared image feature extraction and compensation model establishment is a preliminary exploration of dust influence. In future research, we will consider extracting more infrared thermal image

features that help to analyse the influence of dust and exploring whether it is possible to introduce other methods to quantify the measurement errors caused by dust.

## V. CONCLUSION

Improving the measurement accuracy of infrared thermal imager is essential to extend the application of infrared thermal imager. In this paper, three groups of dust experiments were carried out to correspond to the three kinds of dust interference: dust on the surface of the measured object, dust on the lens of infrared thermal imager and dust in the optical path, and the experimental results show that the dust has a non-negligible influence on the infrared temperature measurement results. Furthermore, this paper extracted the infrared image features that are affected by dust and proposed polynomial regression-based compensation models to quantify the measurement errors caused by dust. The temperature measurement results after compensation demonstrate that the compensation method could significantly reduce the measurement errors caused by dust and improve the temperature measurement accuracy of the infrared thermal imager. Thus, it is possible to establish a procedure to reduce the dust interference when infrared thermal imager is used for temperature measurement. In addition, the compensation idea proposed in this paper helps to expand the application of infrared thermal imager in the temperature measurement processes with dust interference.

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