Effect of Angle of View on Temperature Measurement Error by Multiple Regression Method

Xia Zhao¹*, Xin Jia², Qufei Shi¹, Jian Wu¹ and Peng Li¹

¹Temperature and Humidity laboratory, Beijing Institute of Metrology, Beijing100029, China
²Frontier Science Metrology Centre Department, National Institute of Metrology, Beijing100029, China
Email: 995531040@qq.com

Abstract. Infrared temperature measurement technology has been widely used in industry and agriculture to predict maintenance of electrical equipments due to its advantages of noncontact, harm-free, quick measurement. However, many factors cause errors in infrared thermal measurements, especially the existence of the angle of view causes serious temperature measurement error. Therefore, in this study, based on experimental data, one model related to angle of view and temperature measurement error are established by multiple regression method. Meanwhile, the optimal values of measuring temperature, angle of view is solved by genetic optimization algorithm, which will effectively reduce the measurement error even in the presence of angle of view. Finally, the results of multivariate regression model can effectively compensate for the measurement error, and the correctness of genetic algorithm are verified by experiments. The method proposed in this paper will effectively improve the measurement accuracy, and provide new research method to predict measurement errors for the actual operator of infrared thermal imager.

Keywords. Angle of view; temperature measurement error; multivariate regression model.

1. Introduction
Infrared temperature measurement technology has been widely used in industry and agriculture to predict maintenance of electrical equipments due to its advantages of noncontact, harm-free, quick measurement. [1-6]. It is known from previous results that since the infrared radiation energy received by the detector is very related to the field of view angle, it has a great impact on the temperature measurements error, meanwhile the angle of view is inevitable in practical measurements and applications. Recently, researches also have been evaluated the influence of the angle of view on the measurement accuracy of thermal imagers, they found that it will bring measurement error to the results [7]. In addition, the relationship between field of view and measurement error has not been investigated in detail. These errors can make the thermographer to misdiagnose error. For example, in a thermal image temperature test, an angle of view of 60℃ results in 4%-5% of temperature measurement errors [8]. For normally operating electronics, when the operating temperature exceeds the ambient temperature of 50°C [9], the measurement error at 5 °C will occur. Furthermore, a temperature deviation above 4°C predicts the operational failure of electronic devices [10]. On the other hand, infrared thermal imager technology has been also widely used in the monitoring of animal
temperature to prevent animal disease. However, given the positional uncertainty of the tested object and the poor test environment, the error caused by the angle of view is an important reason for limiting the measurement accuracy.

In this study, the relationship between temperature measurement error, measuring temperature and angle of view are analyzed. One model based on experimental data are built to improve the infrared measurement accuracy by multiple regression method and geometric optimization algorithm. Then the errors of measurement results caused by view angle are compensated, which verify the feasibility of these methods. This study provides us a new method of timely reduce the impact of the field of view angle on the infrared temperature measurement by using multiple regression method and genetic optimization algorithm.

2. Methods
As shown in figure 1, selecting the infrared thermal imager (FOTRIC 226s) as experimental installation produced by Beijing Shenzhou Technology Survey Technology. The basic parameters are shown in table 1. In order to avoid the influence of self-radiation and environmental change on the measurement results, a blackbody with high emissivity 0.999 is selected as the radiation source to study the effect of the field of view angle on the infrared temperature measurement results.

![Figure 1. Experimental conditions for measuring the angle of view.](image)

| Characteristic                  | Thermal Imager |
|--------------------------------|----------------|
| Manufacturer                   | FOTRIC         |
| Resolution                     | 0.1°C          |
| Uncertainty from catalogue     | 2°C            |
| FOV (Field of View)            | 25°C*19°C      |
| Focal Plain Array size         | 512*384        |
| Thermal image pixel values     | 20 million     |

First, in order to better evaluate how the different angle of view effect the temperature measurement results under different temperature measurement conditions, and other parameters that could influence the measurement results are mitigated. Therefore, experiments are conduct in
laboratory environments, in which the ambient temperature is constant, the ambient temperature is 25°C, atmospheric humidity is 55% RH. The following experimental conditions are also established:

The distance between blackbody and thermal imager: keep constant at 2 m.

In order to analyze how the view field angle affect the accuracy of infrared temperature measurement results more clearly, the reference temperature and relative temperature are used to analyze the results of measurements. The reference temperature is defined as the temperature with an angle of 0°C. The relative temperature is the ratio of measured temperature to reference temperature. The temperatures of the blackbody are set to 30°C, 35°C, 40°C, 45°C. And at each measuring temperature, the influence of different view of angles on the accuracy of temperature measurement is analyzed.

The angle of view (θ₁) is changed by rotating the black body, and the angle of view (θ₂) is obtained by putting the angle block under the black body, viewing angle changes from 0° to +75°, ranging in steps of 5°. Viewing angles over 75° are not practical because they would parallel to the emission plane. Each measurement is repeated three times under any viewing angle to ensure the precise of the experimental data.

3. Results

3.1. Association Between the Error, Viewing Angle and Measured Temperature

As shown in figure 2, the curves of the variation of the relative temperature changed with the angle of view (θ₁, θ₂) at four reference temperatures are presented. The angles of view (θ₁, θ₂) at different rotation directions show the same change trend. The relative temperature is close to 1 and shows little change in temperature as the angle of (θ₁, θ₂) rise from 0° to 45°, indicating that within this range of angle, the change of angle has almost no relationship with the experimental data results. But with the field of view angle over 45°, the relative temperature is less than 1 and starting to fall down as the angle of view range from 45° to 75°, implying that it is likely to cause the error of temperature measurement when the angle of view exceeds 45°, meanwhile with the angle of view increases, the error decreases more and more sharply. At this time, the change of angle of view has a very serious effect on the measurement error. They also obtained similar conclusions and similar curves, stating that the measured temperature has close relationship with the setting temperature and view field angle.

![Figure 2. Relative temperature alters with viewing angle at three setting temperatures.](image_url)

The mathematical model is established by the multi0variable regression method as follows:

\[
T_r = 24.5189 \cdot \theta^2 + 0.0007 \cdot T_M^2 + 0.0179 \cdot \theta - 0.2602 \cdot T_M - 0.3483 \cdot \theta \cdot T_M + 0.0082
\] (1)
where $T_M$ is the measured temperature, $T_R$ indicates the reference temperature (the temperature is equal to 0° of angle); $\theta$ is the angle of view. Table 2 shows that in the multiple regression test results, the $R^2$ is 0.9724, $p<0.00001$, indicating that the mathematical model has certain significance, and the error caused by the viewing angle can be achieve effective improvements when the angle of view range from 10° to 75° and temperature varies between 30 °C and 45°C.

Table 2. Result of inspection.

| $R^2$ | F       | $p$      | $s^2$ |
|-------|---------|----------|-------|
| 0.9724| 274.7091| 0<0.00001| 0.2122 |

The factors affecting measurement results is not only the measuring temperature and viewing angle, the different field of view will also cause different measurement errors. The effect of different field of view on the measurement errors will also be systematically analyzed as follows, it will help to assess the significance of difference arising from different field of views.

3.2. Measurement Temperature Prediction and Error Optimization

Shown as figure 2, results show that the measurement error is rapidly accelerated when the angle of view ranges from 45°~75°, in order to reduce the measurement error and investigate how the measured temperature and viewing angle affect the measurement error results, the reference temperature and measurement temperature need to be consistent as far as possible. Based on multiple regression equations, the optimum reference temperature and viewing angle can be predicted by using genetic optimization algorithm, when the angle of view ranges from 0° to 75°, and the temperature ranges from 0℃ to 50℃.

According to the equation (1), the optimization condition can be described as follows:

$$\min = T_R - T_M$$

(2)

Then, according to equations (1)-(2), the fitness function is established by using genetic algorithm toolbox, shown as follows:

function $y=Temperature(x)$

$y=24.5189*x(1)^2+0.0007*x(2)^2+0.0179*x(1)-0.2602*x(2)-0.3483*x(1)*x(2)+0.0082-x(2)$

Meanwhile, in the command line of MATLAB, enter the Temperature's formula, the minimum value of $T_R-T_M$ can be achieved. The running process is shown in figure 3.

[x fval]=ga(@Temperature,2);

Figure 3 displays the optimal process of measured temperature. When the field view is constant at 28°, as the program runs, the average value approaches to the optimal value, the optimization process ends when the number of iterations is 100.

And when the measured temperature is 27.5°C, the angle of view is 13.5°, the best fitness value (final optimization value) of $T_R-T_M$ is 0.066°C, meaning when the angle of view is greater than 45°, measured temperature is 27.5°C, the error between the measured value and the reference value is minimal.
3.3. Experimental Validation

In order to verify the correctness of the two multivariate regression model and the genetic optimization algorithm, experimental verification is necessary.

First, the influence of measuring temperature and angle of view on measuring results is analyzed, the measurement temperature is set to 36℃ and field view of len with larger field view (28℃) is selected to verify the correctness of the model results when the angle of view ranges from 0° to 75°. The measurement results and the model fitting curve are obtained, shown in figure 4.

The correctness of genetic algorithm is verified by setting the temperature value at 27.5℃ and the angle is 13.5°, check if the error between the reference temperature and the final measured temperature is 0.066℃, as shown in table 3.

In order to reduce the effect of the viewing angle on the measurement results, a larger angle of view of 28 °is selected. Shown as in figure 4, when the measured temperature is set to 36℃, the experimental results are in good agreement with the model fitting results, the temperature variation trend is similar to the experimental results in figure 2. Compared with the experimental results, the simulation results are closer to the reference temperature, which indicates that the model of multiple regression from equation (1) can compensate for certain measurement errors.

From table 3, we can all deduce that compared with model calculation, experimental results based on genetic algorithm will result in smaller error of 0.06, which accordance with the results of Genetic Algorithm. From this point of view, the correctness of genetic algorithm is verified directly. If the measurement temperature is 27.5 ℃ and the angle of view is 13.5°, the measurement value is same as the results without error of angle view.
Table 3. Experimental verification of the optimization for measured temperature.

| Measured temperature (27.5°C) | Experimental measurements | Model calculation | Genetic Optimization Algorithm |
|-------------------------------|----------------------------|-------------------|-------------------------------|
| Field view (28°)              | 27.2°C                     | 27.3°C            | 27.44°C                       |
| Angle of view (13.5°)         | 0.3°C                      | 0.2°C             | 0.06°C                        |
| Error                         |                            |                   |                               |

The above results show that on the basis of multivariate regression model, genetic algorithm can effectively select the optimal measurement conditions, reduce the measurement error, and provide better prediction for the calculation results.

4. Conclusions
The error caused by the viewing angle and measured temperature are decrease by the real-time solution and multiple regression method. Based on the multivariate regression model, the best measured temperature and field view can be selected by using genetic algorithm, at this time, even if there existing angle and view, the measurement error can be effectively controlled. The correctness of the multivariate regression model and genetic algorithm is verified by design experiments, the accuracy of temperature measurement is greatly improved, and the measurement error is effectively reduced.

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