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A method for improving temperature measurement precision on the uncooled infrared thermal imager

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ABSTRACT

In order to improve temperature measurement precision of the uncooled infrared thermal imager, aiming at the influence of the thermal imager internal radiation, a method is proposed based on voltage compensation in this paper. Firstly, combining the principle of uncooled infrared thermal imager, radiation of tested object is converted to voltage values, the voltage values are converted to grey value can be measured, and thus the relationship between radiation of tested object and grey value is established. Secondly, according to the relationship between radiation and grey value, a model about uncooled infrared thermal imager temperature measurement is established. A formula for computing the true surface temperature of objects is given. Coefficients are acquired in the temperature measurement formula by collecting the infrared image data of standard blackbody. Finally, in order to verify the correctness of the compensation method, an experiment about blackbody is conducted in this paper. The experiment results show that this method can effectively reduce the relative error of the thermal imager temperature measurement.

1. Introduction

Uncooled infrared thermal imager has many clear advantages such as non-contact measurement, no damage, and wide temperature range, measurement results visual in image, low power consumption, and good portability. Increasing attention has been paid on it recently [1,2]. Uncooled infrared thermal imager has been the most widely infrared temperature measurement instrument. However, as the serious influence of the detector temperature change, the measurement results can not meet the requirements of high precision temperature measurement. The application scope of uncooled infrared thermal imager is limited as result. The improvement of the temperature measurement precision on uncooled infrared thermal imager is very significant for developing of application field.

At present, a lot of researches have been done in order to improve the temperature measurement precision of uncooled infrared thermal imager. Helfrish et al. used two-point calibration method for correcting no uniformity of uncooled infrared focal plane arrays. The relationship between infrared image grey value and temperature was obtained by measuring the different temperature of blackbody. On the basis of this, the gain and offset correction were calculated [3]. By improving the method of two-point calibration, the multi-point calibration method was proposed by Milton et al. The response curve of detector was reasonably divided into several segments. Then every segment was corrected by using the two-point correction method respectively. Multi-point calibration method further increased the calibration accuracy [4]. Scribner et al. used artificial neural network for reducing

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the influence of heterogeneity on temperature measurement precision. Firstly, the expectation error values were input. Then, the error values were transmitted forward. Finally, the automatically modifying of weights can be realized. The efficiency of the correction was improved [5]. On the basis of classical Back-Propagation (BP) artificial neural network, a method called normalization of the BP artificial neural network correction was developed by Torres et al. Before the implementation of classical BP correction algorithm, pixels value input image was normalized and became the value around 1. Finally the data was reduced. This method overcame the difficulty that the practical application was limited due to the difficult selecting of the step length in classic BP algorithm [6]. The research of uncooled infrared thermal imager started rather late in our country. Therefore, the achievements are relatively backward. The relationship of typical response wavelength and it is detect temperature range were discussed. The conclusion that under the condition of identical sensor performance, different wavelengths of the probe temperature detection perform differently was draw by Sheng et al. This conclusion has great significance for choosing different detectors reasonably [7]. The effect of environmental object on infrared temperature measurement was discussed by Zhang et al. Theoretical calculation formula was proposed about tested object real temperature [8]. Bai et al. used a new method for improving the temperature measurement precision. In this method, the value of n in calculation formula about double reference body was changed. This method can accurately measure the emissivity of tested object [9]. The effect of radiation of the sun on infrared temperature measurement error was analyzed by Liu et al. The temperature measurement precision was improved [10]. The influence of distance on temperature measurement was analyzed by Su et al. The fixed relationship between measuring distance and temperature measurement precision was proposed [11].

Temperature measurement precision of uncooled infrared thermal imager is increased in some degree by considering the detector heterogeneity, measured emissivity of object, the environmental temperature, response spectrum, measuring distance and other factors. In this paper, the precision increases by eliminating the interior radiation of the uncooled infrared thermal imager on the result of temperature measurement. By collecting the standard blackbody infrared data, the relationship is established among infrared image pixels value, blackbody temperature, environmental temperature and the temperature variable of thermal imager. The absolute temperature on the surface of tested object can be measured accurately. The method proposed in this paper has the advantages of simple operation, widely applicable scope. The feasibility of the method is proved by the experimental results.

2. Proposed thermal imager model

Radiation will be integrated by detector in working wavelengths. Then, the radiation is transformed to corresponding voltage signal. The radiation power corresponding with voltage values V_s is:

$$\begin{aligned} V_s &= \int_{\lambda_1}^{\lambda_2} P_\lambda R_\lambda \mathrm{d}\lambda \\ &= A_R \int_{\lambda_1}^{\lambda_2} E_\lambda R_\lambda \mathrm{d}\lambda \\ &= A_R A_0 \mathrm{d}^{-2} \int_{\lambda_1}^{\lambda_2} [\tau_{\alpha\lambda}\varepsilon_\lambda L_{b\lambda}(T_0) + \tau_{\alpha\lambda}(1-\alpha_\lambda) L_{b\lambda}(T_U) \\ &\quad + (1-\tau_{\alpha\lambda}) L_{b\lambda}(T_a)] R_\lambda \mathrm{d}\lambda \end{aligned} \tag{1}$$

where ε_λ is spectral emissivity, α_λ is absorption of spectral surface, $\tau_{\alpha\lambda}$ is atmospheric transmissivity, $1-\tau_{\alpha\lambda} = \varepsilon_{\alpha\lambda}$ is atmospheric emissivity, T_0 is absolute temperature on the surface of tested object, T_U is environmental temperature, T_a is atmospheric temperature, A_R is area of thermal imager lens, A_0 is visual area of the tested object when space angle of thermal imager is minimum, d is the distance from the thermal imager to the tested object, R_λ is the responsivity of the detector, λ_1 and λ_2 are working bands of the thermal imager, P_λ is radiation power of working wavelength incident to detector, E_λ and L are radiation illuminance and radiation luminance respectively receives by uncooled infrared thermal imager.

When the working environmental temperature of detector differs from environmental temperature of factory calibration, measurement results will be affected by radiation of detector. $V(\Delta T_d)$ represents the change of voltage which is caused by temperature change T_d of detector. As infrared thermal imager working waveband studied in this paper is 7.5 μm to 14 μm, ε_λ, α_λ and $\tau_{\alpha\lambda}$ are irrelevant to λ. The response voltage V_s of infrared thermal imager can be shown as:

$$\begin{aligned} V_s = A_R A_0 d^{-2} \Big\{ \tau_\alpha \Big[\varepsilon \int_{\lambda_1}^{\lambda_2} R_\lambda L_{b\lambda}(T_0)\mathrm{d}\lambda + (1-\alpha)\int_{\lambda_1}^{\lambda_2} R_\lambda L_{b\lambda}(T_U)\mathrm{d}\lambda \Big] \\ + (1-\tau_\alpha)\int_{\lambda_1}^{\lambda_2} R_\lambda L_{b\lambda}(T_a)\mathrm{d}\lambda \Big\} + V(\Delta T_d) \end{aligned} \tag{2}$$

Because the object can be regarded as grey body in nature, $\varepsilon = \alpha$. Assuming $K = A_R A_0 d^{-2}$, $f(T) = \int_{\lambda_1}^{\lambda_2} R_\lambda L_{b\lambda}(T)\mathrm{d}\lambda$, $V(T) = Kf(T)$, Eq. (2) is transformed into:

$$V_s = \{\tau_\alpha[\varepsilon V(T_0) + (1-\varepsilon)V(T_U)] + (1-\tau_\alpha)V(T_a)\} + V(\Delta T_d) \tag{3}$$

According to the principle of thermal imager, voltage signal V_s is converted into pixels value of infrared image by A/D transition circuit of infrared detector. The relationship between output voltage and the image pixels value is established as follows [12]:

$$G(T) = K_1 V_s + K_2 \tag{4}$$

where K_1 and K_2 are constant that represent system gain and compensated gain respectively. Eq. (3) is taken to Eq. (4):

$$G(T) = \tau_\alpha[\varepsilon G(T_0) + (1-\varepsilon)G(T_U)] + (1-\tau_\alpha)G(T_a) + G(\Delta T_d) \tag{5}$$

where $G(T)$ is the thermal image pixels value for accessed direct of object, $G(T_0)$ is pixels value corresponding to absolute temperature of the tested object surface, $G(\Delta T_d)$ is pixels value corresponding to compensation voltage value $V(\Delta T)$, $G(T_U)$ is pixels value corresponding to environmental temperature, $G(T_a)$ is grey value corresponding to atmospheric radiation. When the distance between tested