Infrared Physics & Technology 77 (2016) 375–381

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Regular article

The research on the effect of atmospheric transmittance for the measuring accuracy of infrared thermal imager

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HIGHLIGHTS

- The influence of atmospheric transmittance on the infrared thermal imager is analyzed.
- The atmospheric transmittance model of infrared thermal imager is established.
- The atmospheric transmittance model can improve the measuring accuracy effectively.

ARTICLE INFO

Article history:
Received 26 March 2016
Revised 17 June 2016
Accepted 19 June 2016
Available online 22 June 2016

Keywords:
Infrared temperature measuring
Atmospheric transmittance
Absorption
Scattering
Attenuation

ABSTRACT

The effect of atmospheric transmittance on infrared thermal imager temperature measuring accuracy cannot be ignored when the object is far from infrared thermal imager. In this paper, a method of reducing the influence of atmospheric transmittance is proposed for the infrared thermal imager. Firstly, the temperature measuring formula of infrared thermal imager and the effect of atmospheric transmittance on temperature measuring accuracy is analyzed. According to the composition of the atmosphere, the main factors influencing the atmosphere transmittance are determined. Secondly, the temperature measuring model of infrared thermal imager in sea level is established according to the absorption of water vapor and carbon dioxide, the scattering of air molecules and aerosol particulate, and the attenuation effects of weather conditions such as rain and snow. Finally, the correctness and feasibility of the proposed model is verified by the comparison experiments of four different environmental conditions. According to the experiments, the temperature measuring accuracy of the infrared thermal imager is improved.

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1. Introduction

In recent years, due to the strong ability of detect, long detection distance and other advantages, the application scope of infrared thermal imager is expanding gradually. The measuring distance of infrared thermal imager can range from a few meters to thousands of meters. In the military, key cultural relic area, airports and other places, the infrared thermal imager has a promising future. In ⟨⟨2016–2021 Internet + infrared imager markets operation mode analysis report⟩⟩, the new opportunities and challenges faced by the traditional infrared thermal imager enterprises in the new situation are discussed. A new thinking of the integration of the Internet with the infrared thermal imaging system is produced. By then, cloud computing will be widely used [1–3]. The infrared radiation attenuation is caused by atmospheric to some degree when the infrared thermal imager is far from the object [4]. According to the attenuation, the measuring accuracy of the infrared thermal imager is influenced. So, in order to improve the measuring accuracy of the infrared thermal imager, the research on the effect of atmospheric transmittance for the measuring accuracy of infrared thermal imager has an important significance [5,6].

When the infrared radiation is transmitted a long distance in the atmosphere, the attenuation of infrared radiation including the effects of atmospheric absorption and scattering, aerosol molecule scattering and rain particles happens. Shi et al. in China Institute of Atmospheric Physics did correlative research about concentration of carbon dioxide, water vapor and gas particle [7]. The research laid the foundation for researching the influence of atmosphere on infrared radiation. Wang et al. studied the positioning influence of atmospheric refractive index on optical satellite image [8]. Jones found that temperature, air pressure and carbon

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http://dx.doi.org/10.1016/j.infrared.2016.06.025
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dioxide concentrations have an effect on the refractive index of the atmosphere [9]. K method is widely used in atmospheric radiation when calculating the atmospheric molecular absorption [10]. The optical thickness formula of atmospheric molecules is obtained through fitting the experimental data by Frohlich and Shaw [11,12]. This formula also was used to calculate the optical thickness of atmospheric Rayleigh scattering by Liu and Qiu [13]. The optical thickness model of atmospheric molecular scattering was proposed by Bodhaine and Wood [14]. According to the Mie scattering theory, the solving method of scattering phase function is studied [15,16]. Considering the influence of atmospheric aerosol and turbulence, the calculation method of target detection was given [17,18]. Han presented a calculation of the transmittance method based on the atmospheric spectral radiance, and the equation of atmospheric transmittance was established [19]. An improved 6S code for atmospheric correction based on water vapor content was analyzed by Zhang et al. [20].

The scholars at home and abroad just analyzed or corrected one factor in atmospheric. The influence factors on atmospheric transmittance will be considered into this paper. These factors include absorption of water vapor and carbon dioxide in the atmosphere, scattering of aerosols such as atmospheric molecular and aerosol, and weather conditions such as rain and snow. Transmission model of atmospheric transmittance in sea level is established. According to the transmission model, the measuring accuracy of infrared thermal imager is improved. And the correctness and feasibility of the model is verified by experiments.

2. The influence of atmospheric transmittance on temperature measuring accuracy of the infrared thermal imager

The temperature measuring formula of infrared thermal image is:

$$T_0 = \left\{ \frac{1}{\varepsilon} \left[\frac{1}{\tau_a} T_r^n - (1-\varepsilon) T_u^n - \left(\frac{1}{\tau_a} - 1 \right) T_a^n \right] \right\}^{1/n} \tag{1}$$

where T_0 is the true temperature of measured object, ε is the emissive of measured object, τ_α is atmospheric transmittance, T_r is the temperature measured by infrared thermal imager, T_u is environment temperature, T_a is atmospheric temperature, n is a constant related to the wavelength of infrared thermal imager. n is 9.2554 when the wavelength is 3–5 μm, and n is 3.9889 when the wavelength is 8–12 μm.

Eq. (2) is the differential form of Eq. (1). Temperature measuring error is obtained:

$$\begin{aligned} \frac{dT_0}{T_0} = \frac{1}{\varepsilon} \Bigg\{ & \frac{1}{\tau_a} \left(\frac{T_r}{T_0} \right)^n \frac{dT_r}{T_r} - (1-\varepsilon) \left(\frac{T_u}{T_0} \right)^n \frac{dT_u}{T_u} - \left(\frac{1}{\tau_a} - 1 \right) \left(\frac{T_a}{T_0} \right)^n \frac{dT_a}{T_a} \\ & - \frac{1}{n} \left[1 - \left(\frac{T_u}{T_0} \right)^n \right] d\varepsilon - \frac{1}{n} [\varepsilon + (1-\varepsilon)] \left(\frac{T_u}{T_0} \right)^n - \left(\frac{T_a}{T_0} \right)^n \Bigg\} \frac{d\tau_a}{\tau_a} \end{aligned} \tag{2}$$

According to Eq. (2), the temperature measuring error of infrared thermal imager is affected by atmospheric transmittance τ_a.

All of the radiation emitted by objects must get though atmospheric attenuation when reach the infrared optical system. The attenuation is called atmospheric transmittance. Some molecules in the atmosphere have a vibration-rotation resonance frequency with the infrared spectral region, and a pure rotational spectral band. These rotational can absorb the infrared radiation. These molecules are water vapor, carbon dioxide, ozone, nitrous oxide, methane, carbon monoxide, and so on. The water vapor, carbon dioxide, ozone has strong absorption bands which can cause the absorption in the atmosphere. And they have a fairly high concentration. Only when the radiation through a long distance or through a large concentration of air, the nitrous oxide, methane and carbon monoxide molecules of this class show a significant absorption. However, in the low altitude below 20 km, the ozone content is usually one of the hundreds of millions of points. So the absorption of water vapor and carbon dioxide is considered in this paper.

The scattering is produced due to the inhomogeneity of the medium. The gas molecules and the density fluctuation in the atmosphere, all kinds of suspended particles are the atmospheric scattering elements. The process of scattering can be regarded as the collision process between the photons and the scattering elements. For simplicity, only the elastic collision is considered. The spectral distribution of radiation energy does not change after scattering. Namely, pure scattering does not cause the total radiation energy loss. But the original spatial or polarization state will be changed by radiation energy. Thus, the radiation is attenuated in the original direction or in some kind of polarization mode. In the infrared region, with the increase of the wavelength, the scattering attenuation decreases gradually. But in the absorption of a very low atmospheric window area, relatively speaking, the scattering is an important reason for attenuation. The scattering intensity is closely related to the concentration, the size and the wavelength of the radiation in the atmosphere.

The transmission of infrared radiation will be impacted by rain and snow greatly. In the atmospheric window region, an experiment using infrared spectral radiometer was held by Wei and Liu under the condition of rainfall [21]. From the results, it can be seen that rain has a great influence on the attenuation of infrared radiation. And it is closely related to the intensity of rainfall. The quantitative relationship of infrared radiation attenuation in the rainy day is analyzed according to the results.

Comprehensive above analysis, in view of the different influence of various components in the atmosphere on the infrared radiation, the main factors is considered in this paper: absorption of water vapor and carbon dioxide, scattering of atmospheric molecules and aerosols, and attenuation of rain and snow. It is very important to establish a model for the research of atmospheric transmission.

3. The temperature measuring model of infrared thermal imager based on atmospheric transmittance

The content of water vapor is high in the lower air. The absorption of water vapor can be expressed with a drop of water w:

$$w = w_0 * S \tag{3}$$

When the radiation distance (sea level) is 1 km, w_0 is the length of water column (mm/km) after the water vapor is condensed into the liquid water. S is transmission distance.

$$w_0 = H_r \times H_a \tag{4}$$

where H_r is relative humidity. H_a is content of saturated water vapor. That is the perceptible water when relative humidity of the air is 100% at a certain temperature.

Substituting Eq. (4) into Eq. (3), the content of water vapor after transmitting a certain distance in sea level is:

$$w = H_r(0) \times H_a \times S \tag{5}$$

The content of water vapor in the atmosphere has been given by Eq. (5). Table 1 is the data of the relationship between the water vapor content in the sea water and the average atmosphere transmittance.

The data above are fitted (wavelength is 3–5 μm). The fitting function of the water vapor content and the average atmosphere transmittance is obtained. According to the fitting function, the average atmosphere transmittance at any water vapor content can be calculated.

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