

The Infrared Multispectral Image Simulation Research Based on 3D Scene

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Abstract—A method of generating infrared multispectral simulation images by 3D scene is presented. The infrared images at any observation angle of the scene and a data cube of simulation images of specific waveband could be generated by the method. Some experiments have been done in waveband 3~5 μm to generate a data cube involving 401 infrared simulation images in the wavelength step 0.005 μm , and the experiments results show that the simulation method presented in this paper could generate infrared multispectral images data cube rapidly. A way to reflect the differences while the observation angle changed is mentioned in this paper.

Keywords- infrared multispectral simulation, the data cube, self-radiation

I. INTRODUCTION

Multi-spectral imaging technology is the new generation of optical-electronics detection technology, and the hot spot in current research and development. The multi-spectral image can make the image information and spectral information together to provide more useful information. The multispectral image can provide not only the 3D scene information as a normal image, but also the spectral radiation information along with wavelength distribution. Multispectral data could form a data cube like figure 1 with strong anti-interference, which can greatly improve the target detection capability and be widely used in military and civil fields^[1].

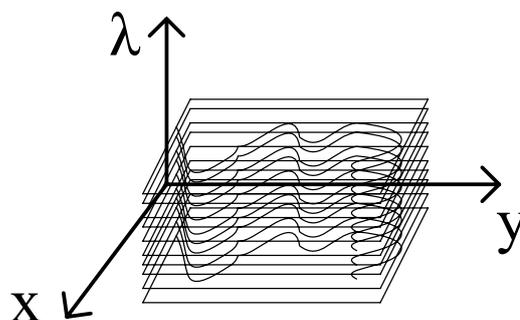


Figure 1. the data cube

Due to technical reasons, most multispectral imaging instruments are controlled by developed countries, and our country only own very few equipment, so it has certain difficulty for multispectral image acquisition. However, related research of multispectral characteristics based on targets and background requires a lot of multispectral images for verification and experiment, therefore how to produce realistic multispectral images by simulation become an urgent need, especially multi-spectral images in the infrared bands.

There are many domestic scholars on the research of IR multispectral image simulation field, but basically focused on the multispectral image generating research from 2D image, such as a 8~12 μm band infrared multispectral image generation method from RGB image proposed by Xu Hong^[2] and a 24 hours a day infrared image sequence generation method from RGB image proposed by Chen Shan^[3], et al.. These researches are all valuable, but a lot of information was drop away to simplify the research process. Limited by the limitations of 2D images, it is impossible to generate omnibearing simulation images of the scene.

In order to solve the problem, this paper presents an infrared band multispectral image generation method based on 3D scene, by which IR images could be acquired in certain wavelength or specified waveband. The method can not only reserve most of the information of the scene, but also generate multi-angle and comprehensive multispectral images to meet the target image acquisition requirements at any Angle.

II. THE SIMULATION METHOD

In general, the factors affecting the IR thermal radiation image mainly involving the target self-radiation, solar radiation, ground radiation and atmospheric radiation and some other aspects. The thermal radiation model of the target is set up as shown in figure 2, figure of the solid line represents the target itself thermal radiation, and a dotted line represents the target reflected radiation of the incident radiation. Regardless the atmospheric loss of thermal radiation between the target and the sensor, the final target radiation intensity ($\text{W/m}^2/\text{sr}/\mu\text{m}$) L_{obj} measured by sensor is:

$$L_{obj} = L_{self} + L_{rsun} + L_{rsky} + L_{rground} \quad (1)$$

The equation is controlled by 4 parameters:

L_{self} : the self-radiation intensity of the target

L_{rsun} : the target reflected radiation intensity of the solar radiation

L_{rsky} : the target reflected radiation intensity of the sky

$L_{rground}$: the target reflected radiation intensity of the ground

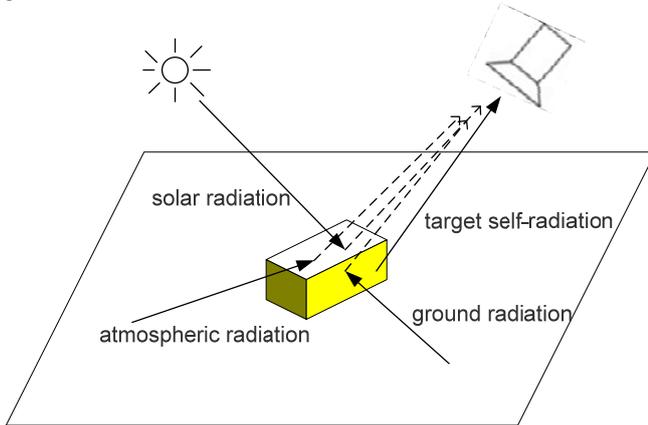


Figure 2. the thermal radiation model of the target

A. the Calculation of the Self-radiation

The radiation intensity of the target in some waveband like $(\lambda_i \sim \lambda_j)$ is the integral for all the radiation intensity of the light in every single wavelength in the waveband:

$$L_{self}(\lambda_i, \lambda_j) = \int_{\lambda_i}^{\lambda_j} L(\lambda) d\lambda \quad (2)$$

According to the Planck's law, the irradiance ($\text{W/m}^2/\mu\text{m}$) of black body is a function of temperature and wavelength:

$$M_b(\lambda, T) = 2\pi hc^2 / \lambda^5 (e^{\frac{hc}{\lambda kT}} - 1) \quad (3)$$

The radiation intensity of black body is

$$L_b(\lambda, T) = M_b(\lambda, T) / \pi = 2hc^2 / \lambda^5 (e^{\frac{hc}{\lambda kT}} - 1) \quad (4)$$

Where h is the Planck constant, and k is the Boltzmann constant, and c is the speed of light, and T is thermodynamic temperature measured in K.

The spectrum radiation intensity of none black body is related to its material:

$$L(\lambda) = L_b(\lambda, T) * \varepsilon(\lambda) \quad (5)$$

Where $\varepsilon(\lambda)$ is the thermal radiation emissivity of the material.

So the self-radiation intensity of the target in some waveband is:

$$L_{self}(\lambda_i, \lambda_j) = \int_{\lambda_i}^{\lambda_j} \varepsilon(\lambda) * 2hc^2 / \lambda^5 (e^{\frac{hc}{\lambda kT}} - 1) d\lambda \quad (6)$$

The radiation intensity of some target with specific material in one single wavelength or in some waveband could be calculated by equation 6.

B. the Calculation of the Target Reflected Environment Radiation

The solar radiation, the ground radiation and the atmospheric radiation totally called environment radiation. The environment radiation reflected by target L_{ratm} is:

$$\begin{aligned} L_{ratm} &= L_{rsun} + L_{rsky} + L_{rground} \\ &= (L_{sun} + L_{sky} + L_{ground}) * \rho(\lambda) \end{aligned} \quad (7)$$

Where $\rho(\lambda)$ is the light reflective in wavelength λ of the material of the target.

Because there are too many factors for environment radiation to consider all of them in the calculation, it is necessary to get assistance from professional software as Modtran^[4] or Cart.

C. The Simulation Experiment

Choose one cooling tower in a power plant in Shenyang area in July as the research target, and build its 3D model shown in figure 3 by Multigen Creator^[5], and simulate its radiation characteristics in waveband 3~5 μm . Consider the cooling tower as a lambertian emitter in the simulation because it is constructed by relatively rough construction concrete, so the target self-radiation is the same in all directions.

Set the atmosphere visibility as 23 km, and the sun zenith angle as 30degree, the solar direct radiation calculated by Cart is shown in figure 4.

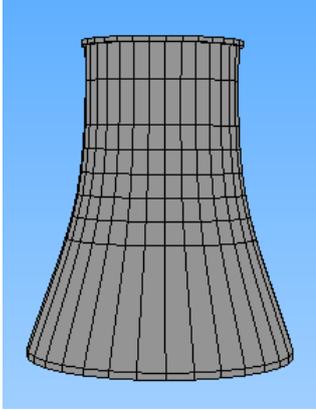


Figure 3. the 3D model of the cooling tower

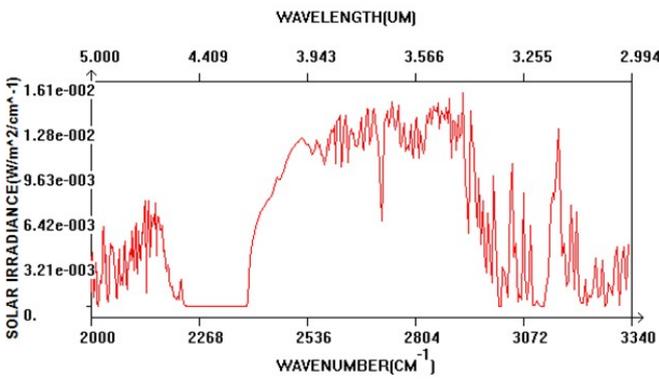


Figure 4. the solar direct radiation in waveband 3~5μm

Set the ground as normal land, and set the temperature as 17°C, then the background radiation is shown in figure 5.

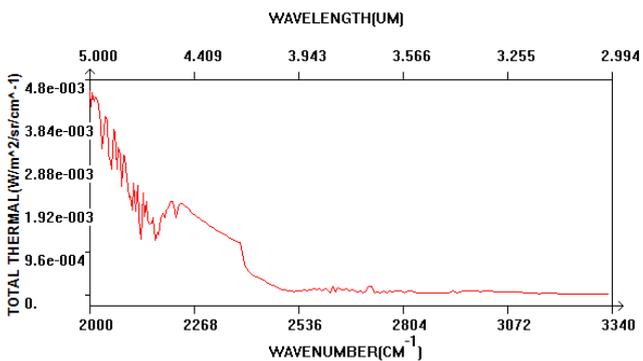


Figure 5. the background radiation in waveband 3~5μm

Set the material of the cooling tower is construction concrete, then acquire the reflectance of the material shown in figure 6 from the ASTER Spectral Library^[6] database from JPL(Jet Propulsion Laboratory), US.

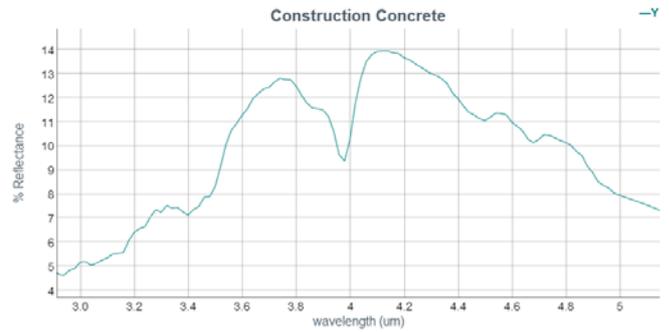
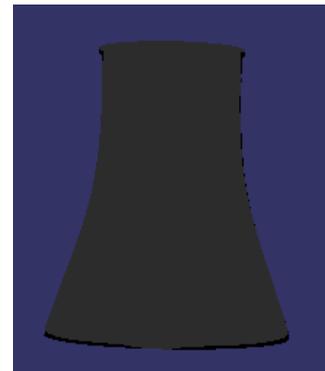
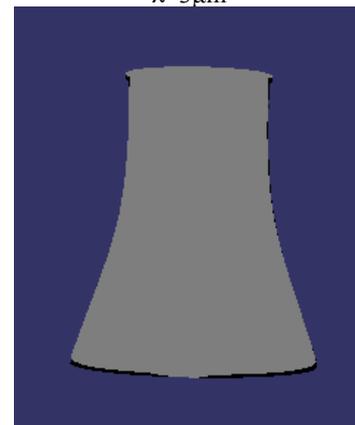


Figure 6. the reflectance of construction concrete in waveband 3~5μm

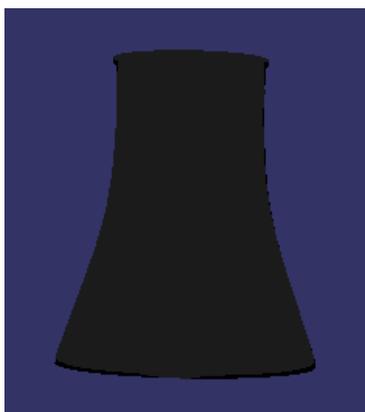
Set the surface temperature of the cooling tower as 25 °C, regardless the atmospheric loss of thermal radiation between the cooling tower surface and the inherent effects of sensor itself, only considering the radiation characteristics on the surface of the cooling tower, get the data cube of 401 infrared simulation images in waveband 3~5μm with $\lambda=0.005\mu\text{m}$ by GLSL^[7]. The simulation images in wavelength $\lambda=3\mu\text{m}$, $\lambda=4\mu\text{m}$ and $\lambda=5\mu\text{m}$ are shown in figure 7.



$\lambda=3\mu\text{m}$



$\lambda=4\mu\text{m}$



$\lambda=5\mu\text{m}$

Figure 7. the simulation images

D. The Analysis of the Simulation Results

The simulation results as shown in figure 7 could identify the radiation intensity of the radiation in different wavelength. And with the method mentioned above, the IR simulation images of the scene in any angles could be generated. But no matter how to change the viewing angle, the simulation results don't have a little change. That's because the radiation intensity in this method just has relationship to the incident intensity. The simulation results are acceptable at night time, because the target radiation mainly depends on the self-radiation and the background radiation which don't have obviously directionality. And because of the directionality of solar direct radiation at day time, the simulation results obviously have too much difference with the actual situation.

At present in most of the simulation calculation, the target is approximated to diffuse reflector, which assumes the radiation reflection intensity of the target are equal in all directions. The assumption is reasonable to self-radiation and background radiation, but not proper to solar direct radiation. The BRDF^{[8][9]} (Bidirectional Reflectance Distribution Function) is a function of incident angle, reflected angle and wavelength like shown in figure 8. It can be used to show the reflection characteristics in different directions of the incident light. BRDF is used here to calculate the target reflection of the solar direct radiation to show the reflection directionality.

III. SUMMARY

The simulation method presented in this paper could generate infrared multispectral images cube in any observation angle, any waveband and any step in wavelength. It could improve the accuracy and reusability of the infrared simulation image greatly. The simulation images in different waveband have different radiation characters, which could be used for target recognition.

It is necessary to calculate the specular reflection of the solar direct radiation. The next step of the work is to do some research on a method to calculating the BRDF values in a realtime way.

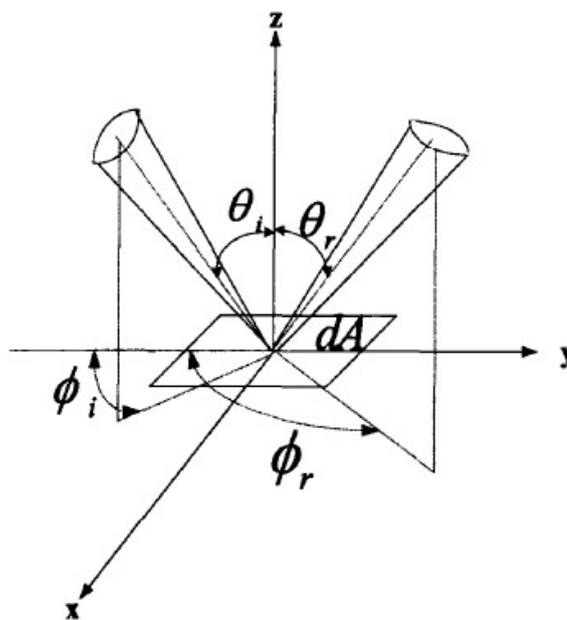


Figure 8. Figure 8: BRDF principle diagram

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