Temperature and emissivity separation algorithm for TASI airborne thermal hyperspectral data

Heshun Wang
Beijing Research Institute of Uranium Geology
Beijing, China
Email: heshun8336@163.com

Qing Xiao, Hua Li, Bo Zhong
Institute of Remote Sensing Applications
Chinese Academy of Science
Beijing, China

***Abstract*-This paper proposed a modified TES algorithm for retrieving land surface temperature and emissivity (LST&E) from Thermal Airborne Spectrographic Imager (TASI) hyperspectral data and the results were validated with *in situ* ground measurements. Firstly, the atmospheric correction of TASI data was performed by MODTRAN model with atmospheric profile extracted from NCEP data which was modified by local meteorological data. Then, the S-G filter was used to smooth the spectral data in order to reduce the noise effect of TASI data. Finally, the Temperature and Emissivity Separation (TES) algorithm was modified to retrieving LST&E from TASI data. The validation results indicated that the derived LST agreed with the ground LSTs well with RMSE lower than 1.5K, and the retrieved emissivity curve showed a good agreement with ground LSEs measured by an Fourier Transform Infrared (FTIR) spectroradiometer.**

Keywords-LST; LSE; TASI; Atmospheric correction; TES.

I. Introduction

Land surface temperature (LST) and Land surface emissivity (LSE) are both key parameters controlling energy exchange in surface-atmosphere system. LSE reflecting the land surface emission feature is widely applied in geological research, mineral mapping and so on. Quantitative remote sensing inversion is an important approach to retrieve LST&E on regional and global scale. As the multi-spectral and hyperspectral thermal infrared sensors appear, deriving the LST&E simultaneously becomes possible. Except for the space-borne sensors such as MODIS and ASTER, various airborne multispectral and hyperspectral thermal infrared sensors play important role on regional survey and scientific research for their flexibility and finer spatial resolution. At the same time, algorithms for extracting LST/LSE information from the data collected by these airborne sensors have been subsequently proposed and yielded satisfactory result [1]-[3]. In domestic, airborne multispectral thermal sensors such as TIMS, MAIS, and OMIS have been applied on many different applications, and scholars employed TES algorithm to retrieve good results of LST and LSE together. However, the emissivity validation using *in situ* data has been barely presented.

TASI is a new generation of commercial hyperspectral infrared sensors released by ITRES, Canada in 2006[4], aiming to the detection of land surface temperature and emission characteristics and applications like mineral mapping, land mining and gas exploration. TASI was firstly imported to China by Beijing Research Institute of Uranium Geology in 2010, and it has been used in several aerial remote sensing experiments. However, there have been few researches on extracting the LST&E from TASI until now. This paper explores the temperature and emissivity separation algorithm for TASI data acquired in "HuaiLai Remote Sensing Comprehensive Experiment" on September 2010; then the algorithm is validated using *in situ* measurement collected in this experiment.

II. Method

The basic problem of temperature/emissivity separation in thermal infrared remote sensing is that there are only N equations from N channels' observations, whereas there are N+1 unknowns (N band emissivities and LST), these equations are obviously underdetermined. To resolve this problem, additional equations should be established. Many researchers have proposed various algorithms such as NEM, Alpha residual, MMD, and the most widely used is TES algorithm [5].

A. Discription of the TES algorithm

The input data for TES include the land-leaving radiance and the down-welling sky radiance acquired from atmospheric correction which will be introduced in the following part. TES algorithm contains three modules: NEM, RADIO and MMD.

NEM module gradually removes the atmospheric residual through iteration to get more accurate LST&E as the initial estimations. RADIO module calculates the radio of channel emissivity and average one then gets a closer emissivity shape which is insensitive to temperature error. MMD module establishes the relationship between the max-min emissivity radio difference and the minimum emissivity so that absolute value could be got from the emissivity shape. The TES algorithm is described in detail in [5].

When TES algorithm is applied to TASI, a new empirical relation should be built because of the difference between the sensors. In order to obtain a representative result, 251 spectra from ASTER and MODIS spectral libraries including water, vegetations, soils and rocks were selected to fit the empirical relation. The fitting result is as follows:

$$\varepsilon_{\min} = 0.9869 - 0.7733 MMD^{0.8494} \quad (R^2=0.991)$$

It should be noted that once MMD is applied to the gray body such as dense vegetation or water, this method would cause big errors. Thus, we set the minimum emissivity to 0.983 instead of using MMD method when MMD is less than 0.032.

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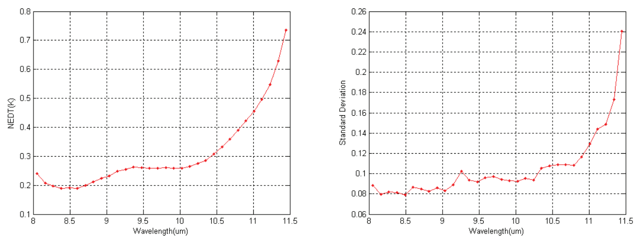
Finally, we use the maximum emissivity to recalculate the temperature and remove the atmospheric residual, and then carry out the three modules mentioned above for another time to get more accurate result.

B. Bands slection in TASI TES algorithm

TES algorithm is effective when the sensor has 4 or more thermal channels, in theory, TASI would get better precision for its more information from 32 channels. However, there are big noises in some channels, which can be seen from the Noise Equivalent Delta Temperature (NEDT) of the sensor (Fig.1(a)). In order to demonstrate the noises of different channels from the image itself, a homogenous area of water about 400 by 400 pixels from TASI image is selected and the standard deviation of these pixels is showed on figure 1(b). It is obvious that the noise become larger as the wavelength increase, especially after 11μm. The involvement of these bands with heavy noise in the TES algorithm would have significantly negative impact on the results. Thus, we try to exclude some channels with heavy noises to improve the results. A numeric analysis is done to select the optimal bands for inversion.



(a) (b)

Figure 1. TASI 32 bands' noise level.(a) The NEDT of TASI; (b) The standard deviation of a homogenous region of TASI image

As it can be seen from Figure 1, the NEDT of different channels increase gradually with wavelength. In the MMD module, larger contrast spectral could yield better results, and the analysis of infrared spectral library shows that emissivity in 8-10μm changes bigger than that in 10-12μm [6], therefore selecting the bands at shorter wavelength for inversion would be more favorable. In view of this, we select the first N TASI bands (N = 5, 6 ...... 32) for temperature/emissivity separation test via simulated data including added random noise.

The root mean square error (RMSE) of the LST&E inversion are shown in Figure 2, we can see that more bands does improve the accuracy of inversion, meanwhile, a corresponding increase of the noises enlarge the inversion error. Numerical analysis result shows that using the first 24 bands of TASI for temperature/emissivity separation would obtain the best retrieval results.

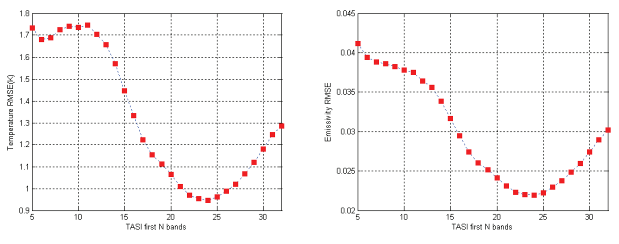


Figure 2. Precision analysis of TASI bands selection in TES

C. Spectral smooth

Land-leaving radiance contains two parts: surface own emission and the reflected atmospheric down-welling radiance. Despite atmospheric downward radiation varies greatly with wavelength, considering it is just a small proportion and the channel width of TASI is relative wide, the land-leaving spectra is overall smooth, on the other hand, the fluctuation introduced by the noise weight more than the atmospheric effect. Thus it is reasonable to smooth the spectral to improve the inversion.

Savitzky-Golay(S-G) filter could eliminate mixed white noise to some extent while keeping the spectral characteristics. For S-G filter is based on the principle of polynomial fitting at a certain window, so the effect of the filtering depends on the degree of the polynomial and the size of the window. When using S-G filter in TASI spectral domain, the selection of these two parameters should in accordance with the noise level and the characteristics of the spectra, heavy noise need a low degree or a big window size and vice versa.

S-G filter test is carried out based on the simulated data and figure 3 shows the comparison of the emissivity of a soil sample retrieved from the data before and after filtering. The result shows that the filtering process makes obvious improvements on both the shape and the absolute value. The presence of noise causes the MMD's increase, so the minimum emissivity is underestimated; consequently, the overall emissivities are smaller than the true value.

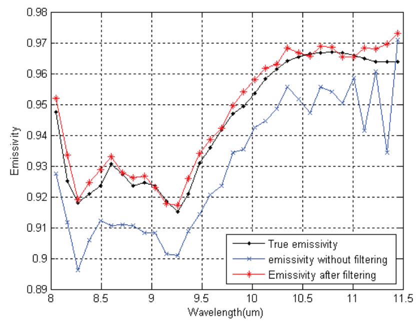


Figure 3. Comparison of emissivity retrieval between before and after filtering

S-G filtering method is then applied to the simulated dataset for temperature/emissivity separation, the temperature RMSE is improved from 1.13K to 0.82K while the emissivity RMSE decreases from 0.025 to 0.018.

III. DATA

A. Introduction to TASI data

The TASI data used in this paper was collected in "Huailai Remote Sensing Comprehensive Experiment" on September 14, 2010. The aircraft flying height is 1,000 meters above ground and the spatial resolution is 1.2 meters. Basic specifications of TASI are shown in Table 1. The experiment area is around "Huailai Remote Sensing Comprehensive Experimental Station" (115 º 46'59 .569 "E, 40 º 20'55 .093" N, 488.3m). This area is a typical Mountain-basin structure in the west of North China and it is a sub-plateau region with various landforms and rich biodiversity; the main land cover types contain farmland, orchards, reservoirs and villages.

TABLE.1 BASIC SPECIFICATIONS OF TASI

Spectral range	8-11.5μm
Spectral resolution	109.5nm（32 bands）
FOV	40°（IFOV=1.2mrad）
Imaging mode	600pixel pushbroom
Detector component	MCT
SNR	5415

B. TASI data pre-processing

The pre-processing of TASI data includes radiometric calibration, geometric correction and atmospheric correction. The first two steps were completed by the software provided by ITRES. Generally, accurate atmospheric correction should be performed with synchronized radio-sounding data and a radiative transfer model. However, there are no sounding data available during the flight, so in this paper we use atmospheric profile extracted from NCEP data which is modified by the local meteorological data. The processing as follows:

1) Spatial and temporal interpolation of NCEP data: NCEP data have a spatial resolution of 1° × 1° derived from the Global Forecast System which run four times a day (0:00,6:00,12:00,18:00 GMT).

2) NCEP profile modification using *in situ* measurement of water vapor content and atmospheric temperature from local weather station: in order to get a more accurate atmospheric profile, we use the air temperature measured by the weather station to modify the NCEP temperature profile; at the same time, the column water vapor content collected from CE318 is used to modify the NCEP water vapor profile.

3) Take the modified profile as the input，run MODTRAN model[7] to simulate the transmission τ_λ, path radiance $L_\lambda^\uparrow$ and the down-welling sky radiance $L_\lambda^\downarrow$. Atmospheric correction is performed according to the following formula:

$$L_s = \varepsilon_\lambda B(T_s) + (1-\varepsilon_\lambda) L_\lambda^\downarrow = \left(L_\lambda - L_\lambda^\uparrow\right)/\tau_\lambda \quad (1)$$

C. In-situ measurement processing

Temperature and emissivity *in situ* measurements were carried out synchronized with TASI observation; the validation sites cover main surface types in this region.

The emissivity measurement was conducted by the BOMEM FTIR spectroradiometer which covers 2-15μm with 1cm^{-1} resolution. Along with the down-welling sky radiance measured through the diffuse golden plate, the target radiance was used to retrieval the emissivity spectral by the ISSTES algorithm [8], and then the spectral curve were converted to TASI channel emissivity for the validation.

Surface temperature was measured by two kinds of infrared radiometers which were calibrated immediately after the experiment, since the radiance acquired by the radiometers included the reflected atmospheric down-welling radiance, the calibrated temperature should remove this part to get more accurate LST, which is conducted as follows [9]:

$$B(T) = \left(B(T_r) - (1-\varepsilon) L^\downarrow\right)/\varepsilon \quad (2)$$

Here, the down-welling sky radiance was obtained in the atmospheric correction; while, the wide-band (8-14μm) emissivity could be got from the in-situ measurement which need to be integrated.

IV. VALIDATION

The first 24 bands of TASI were used for temperature and emissivity separation, and the retrieved temperature is shown in Figure 4, which reflects the temperature distribution of different objects well.

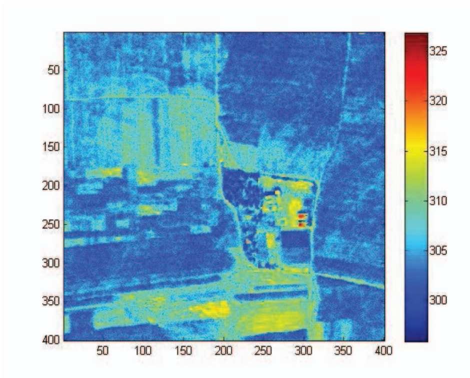


Figure 4. The LST image retrieval from first 24 bands of TASI

In order to validate the retrieval accuracy of the algorithm, the *in situ* measurements are compared with the retrieved results, as Table 2 shows. We compare the results retrieved by 32 bands and 24 bands respectively, which shows that the results using 24-channel are better than those using the 32-channel, especially for dense vegetation. Average RMSE of the retrieved temperature is 1.43K. For different land cover types, the soil and cement road produce better result than the vegetation, this could attribute to the TES algorithm which is based on the relationship between the spectral contrast and minimum emissivity, low contrast spectral such as vegetation will cause larger error in the MMD module than the soils.

TABLE 2. LST VALIDATION RETRIEVED FROM TASI

Site	**Measurements (K)**	**Derived from 32 bands (K)**	**Derived from 24 bands (K)**
cement road	310.06	310.21	310.58
Bare soil	305.30	305.61	305.13
corn canopy	299.83	304.61	301.93
Peanut canopy	304.77	305.10	305.38
Grass land	314.81	313.31	313.40
Bean canopy	309.30	306.99	307.02
RMSE	——	2.26K	1.43K

Retrieved emissivity result is showed on Figure 5. Band 1 (8μm), band 28 (11μm) and band 5 (8.5μm) are selected for

RGB color composite and this figure can clearly distinguishes the vegetation and soil by the difference of their emission features.

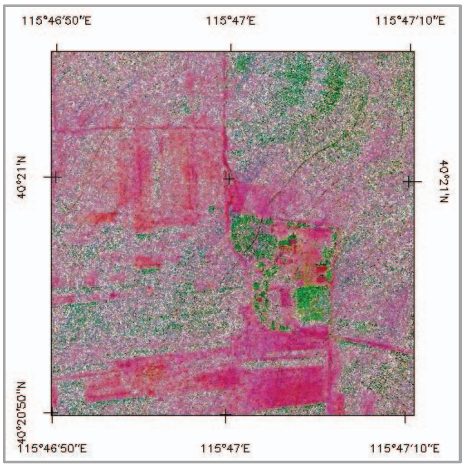
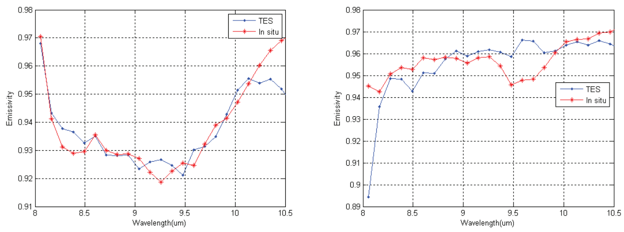


Figure 5. The LSE figure retrieval from TASI

Emissivity results of two typical land surface types are illustrated in Figure 6.



(a) (b)

Figure 6. Validation of TASI retrieved emissivity

Figure 6 (a) demonstrates the retrieved and measured emissivity of a field road which is consist of soil and rocks. We can see that the inversion result agree well with the measured data in 8-10μm, however, when the wavelength large than 10.2μm, the spectral become lower than the measured one obviously, which could be explained for the calibration problem. Figure (b) is the corn canopy emissivity comparison, there is a big deviation at band 1 which could attribute to two aspects, the calibration error and the atmosphere residual which is relative large at this band。

V. CONCLUTION

LST and LSE are important parameters in land surface process, temperature and emissivity separation from the airborne infrared hyperspectral data plays an important role in the surface monitoring and mineral exploration. In this paper, The NCEP data combined with local meteorological data was used to perform the atmospheric correction. Due to difficulties introduced by the random noise of the data, we selected the first 24 bands of TASI through numerical analysis to improve the inversion results, then modified TES algorithm and applied to TASI hyperspectral data. Besides, to overcome the problem of the spectral fluctuation, we used S-G filter to smooth the land leaving radiance, which significantly improved the inversion results. The validation results showed that the RMSE of derived temperature was within 1.43K, Apart from some individual bands with calibration problem, the emissivity of most bands were in good agreement with the ground measurements.

Although we have achieved some preliminary results, there are many problems needed to be addressed in the future. Firstly, we should implement the atmospheric correction based on the TASI image itself in order to free from the dependence on the auxiliary atmospheric data, if so, higher retrieval accuracy will be obtained as well. Secondly, further research should be carried out on the pre-process of TASI data which include eliminate random noise and calibration problem, the random noise problem calls for more appropriate filtering method while the calibration error may be improved by field calibration in following flight campaign.

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