SPACEFLIGHT HYPERION DATA RADIATION CALIBRATION PRELIMINARY STUDY

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KEYWORDS: Hyperion Data, Radiometric Calibration, Calibration Model

ABSTRACT:

Radiometric calibration is the basis of both hyperspectral data applications and quantitative remote sensing. While at present, there is no good and suitable method for radiometric calibration in the aerospace hyperspectral data. The paper uses the highest spectral resolution Hyperion EO-1 satellite data in current world Spaceflight sensor as information source, using a variety of calibration models, which including of the calibration model based on atmospheric radiation theory, conversion model based on the characteristics of the image itself(Flat Field Model, IAR Reflectance Model, Log Residuals Modified Model, e.g.), linear model based on the experience of the ground calibration and so on, implementation Spaceflight hyperspectral data calibration study. Through the above model calibration contrast, and combined analysis with the field measured spectral curve, then we draw the conclusion that the calibration model based on atmospheric radiation theory is the best radiation calibration method for Spaceflight Hyperion data, so we provide the quality assurance for the effective application of Spaceflight Hyperion data.

1. INTRODUCTION

In the last 20 years of 20th century, people achieved a major breakthrough in hyperspectral remote sensing. It blends traditional image dimension and spectral information together, obtaining the continuous spectrum information of each object while gaining ground spatial image, thus laying solider foundation of discerning and differentiating feature class and its components according to feature spectral characteristics. But the first problem we may meet in the application of space Hyperion data is radiometric calibration

Radiometric calibration is the basis of both hyperspectral data applications and quantitative remote sensing. It transforms DNs into reflectance or apparent reflectance, removing all kinds of distortion that brings by atmospheric scattering，absorption， terrain undulate and error of sensor, returning to the original appearance of spectral data. At present, there has been no concern for geo-Information analysis of onboard Hyperion imaging spectrometer data at home and abroad, and in the space hyperspectral data radiometric calibration side, there has been no good and suitable methods.

This article takes the Hyperion data as the information source, using many calibration models to proceed with the space hyperspectral data calibration study, including calibration model that based on the theory of atmospheric radiation, model based on Image own identity conversion (e.g. Flat Field Model [1-2], Internal Average Relative Reflectance Model [3-4], LOG Residuals Modified Model [5]), Empirical Line Calibration Model [6] and so on.

2. MODEL BASED ON IMAGE OWN IDENTITY CONVERSION

The model based on image own identity conversion starts from the image itself, using some spatial locations' pixel brightness of the image to correct and adjust other locations, other bands, aims to achieve the calibration target. Generally, such methods get the relative reflectance of each band. Common methods include dark objective method, Flat Field, The Internal Average Relative Reflectance, LOG Residuals and some transformers of them. Another methods use band characteristics to correct and calibrate relatively, such as regression analysis and histogram.

In the methods above, the dark objective method supposes the existence of dark objectives which the radiance brightness is zero in an image, then subtracts the dark objective brightness value in the corresponding bands by comparing each band histogram, to achieve the purpose of atmospheric correction; Flat field model normalized the image with pixel's average value of which the spectrum and geomorphological features is uniform and flat, using mean value of certain band image, mean value of pixel in all bans, mean value of the image's all bands as sun irradiation, topography factor and normalized constant. IARR normalizes the image with the mean value of full image pixels; LR supposes the radiation value $DN_{i\lambda}$ and the reflectance $R_{i\lambda}$ have equality like this:$DN_{i\lambda}= Ti\ R_{i\lambda}I_{\lambda}$,correcting the image in the logarithm domain by using Log function on both sides. Theoretical basis of inter-band regression analysis lies in the selectivity of atmospheric scattering, promptly, atmospheric scattering affects short wave greatly, little to long wave. Among the bands that unaffected by atmosphere and uncorrected band images, choosing a serials objectives from brightest to darkest, regressing the two bands of each objective.

When using histogram, if there are objectives that the brightness value is zero in an image, such as deep sea water, shade and so on, then the corresponding image's brightness value is zero. To determine the influence of atmosphere and display histogram of certain image, from the histogram we can see that the darkest objective brightness of band m is zero, the difference between band n minimum and band m is the atmosphere influence.

Using the methods above is simple and convenient in computation, it can calibrate feature irradiation relatively in some extent, removes some influence of atmosphere absorption, see figure 1.But universally speaking, the calibration effect is ordinary, and affected by human factor greatly. Same data, choosing different space location pixel value as reference value will get a result as like as chalk and cheese.

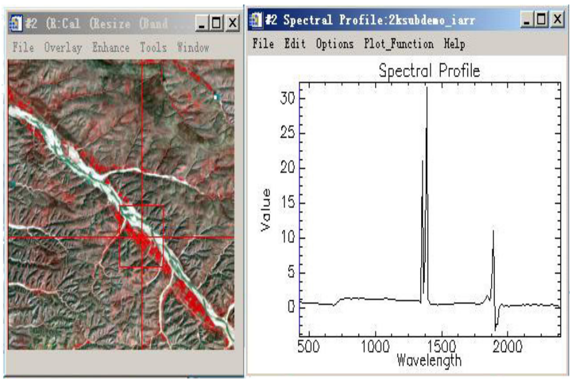

Figure 1 Effect Image by IARR (Vegetation Pixel)

The left image is the color composite of corrected image, R（862.01nm）、G（650.67nm）、B（548.92nm）,the right graph is the longitudinal brightness curve of red line cross center pixel, this pixel is vegetation. This method can only get the relative reflectance among bands, not the true feature spectral curve .so it is not behalf to the information extraction that based on feature spectral curve.

3. EMPIRICAL LINEAR MODEL BASED ON GROUND CALIBRATION -ELC

The empirical linear model based on ground calibration mainly compares measured spectral curve and longitudinal brightness curve, calculating each band's offset and gain value with linear regression, correcting the longitudinal brightness curve to keep the same as the spectral reflectance curve of actual features, thus achieved the radiometric calibration goal. This method requires field ground measurement in parallel with satellite scanning, fitting image data and synchronous or quasi-synchronous measurement features by least square.

According to regression equation to retrieve features' reflectance spectrum [6], regression equation is:

$$L = \alpha + bR \qquad (1)$$

Where α a constant, b is is regression coefficient, R is ground reflectance.

Make $bR=L_G$, stands for ground measured reflectance, promptly the unaffected part by atmosphere, so

$$\alpha = L - LG \qquad (2)$$

Correction formula is:

$$LG = L - \alpha \qquad (3)$$

Every pixel in the image must deduct the influence of α to obtain atmospheric correction image of specific area.

The greatest characteristic of this method is simple and easy to be achieved. Its physical significance is clear. It can correct the impact of atmosphere, illuminance and equipment noise comprehensively, and it has good reconstruction effect. But it needs synchronous or quasi-synchronous spectrum test when acquiring data and the correction effect depends on the calibration points strongly. Moreover, in the scope of the equation, especially mountain areas, the absorption, scattering and neighborhood effect of atmosphere are generally unhomogeneous.Thus it asks a harsh requirement for calibration point, and it is rather difficult when choosing such points.

Beijing Research Institute of Uranium Geology has measured many spectral curves in Dongsheng area. As there are large areas of farmland in Dongsheng, so that reflected in the image is some pure pixels. Here we choose some measured vegetation spectral curve in farmland to do empirical linear regression, see figure 2.

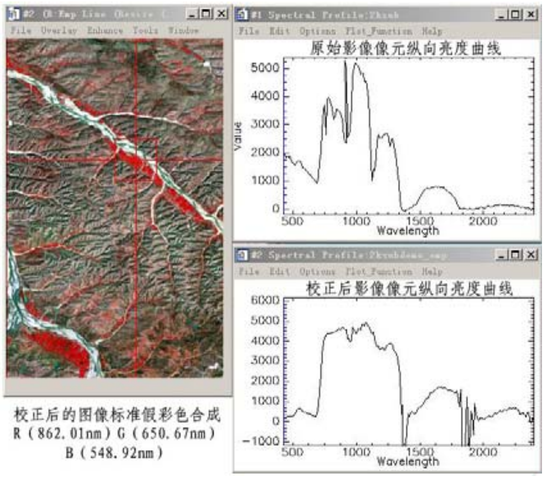

Figure 2 effect image of ELC (vegetation pixel)

4. CALIBRATION MODEL BASED ON THE THEORY OF ATMOSPHERIC RADIATION- FLAASH

The calibration model based on the theory of atmospheric radiation is according to the physical process of radiation transfer, building on the basis of radiation transfer equation, using theoretical formula to proceed with atmospheric correction [8-9].So from this perspective, this model is the best one in current hyperspectral data radiometric calibration. However, strict theoretical model needs measuring many parameters synchronously which are related to atmosphere, and these parameters are difficult to be measured actually, therefore the model mostly adopts flexible methods to set these atmospheric parameters that affects the precision.

Nowadays, there are many radiation transfer models which can be divided into two kinds: MODTRAN4（Moderate Resolution Transmittance Code 4）and 6S(Second Simulation of the Satellite Signal in the Solar Spectrum) [7]。

Another representative ones that developed from MODTRAN4 are ATCOR（Atmospheric Topographic Correction）,ACORN（Atmospheric Correction Now）,FLAASH（Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes）.Model that developed from 6S is ATREM（The Atmosphere Removal Program）.These models can provide a large number of

parameters document lookup table to facilitate users to choose suitable conditions of the atmospheric parameters.
Transmission model inversion method has tight theoretical basis, high accuracy, but needs measuring and inputting atmospheric optical thickness, moisture content, temperature, pressure, air distribution and other parameters of the atmospheric environment.

Based on MODTRAN4, FLAASH can restore surface reflectance of features from hyperspectral image. Unlike other atmospheric correction modules, FLAASH doesn't do atmospheric correction by adding radiation transmission parameters into pre-calculated model database. FLAASH module directly joints with the atmospheric radiative transfer coding of MODTRAN4.Any standard MODTRAN atmospheric model and aerosol model can be used directly, and proceeding with the calculation of surface reflectivity.

FLAASH module can rectify approaching pixel effect while providing the visibility calculation of the whole image. In addition, FLAASH can generate classified image of cirrus and thin cloud to smooth the spectrum and eliminate noise. Atmospheric rectify with FLAASH can be divided into 3 steps. First, obtaining atmospheric parameters from image, including visibility (aerosol optical thickness), aerosol model and atmospheric water vapor content. Since aerosol-algorithm is based on special targets of image, such as water and dense vegetation. In FLAASH, it also continues to use dark objective method, so one image can ultimately obtain one average visibility data; On the other hand, in FLAASH, the inversion algorithm of atmospheric water vapor content is based on the spectrum characteristics of moisture absorption, using band ratio method, therefore, moisture content in the FLAASH is calculated by the pixel. Second, after obtaining atmosphere parameters, gaining reflectance data by solving the atmospheric radiative transfer equation. Finally, in order to eliminate the existed noise in the rectification process, it needs to use smooth spectrum pixels in images to do spectrum smoothing operation on the whole image.

The influence of cloud or cloud shade will bring many problems to atmosphere correction. Cloud covered pixels can not only obtain its reflectivity information, but also reduce the other adjacent pixels' reflectance on different degrees. FLAASH can automatically determine image areas affected by cloud, avoiding from these pixels in the atmosphere correction, and substitute the cloudy area radiation rate with image's mean radiation rate to proceed with follow-up treatment.

FLAASH model divides different regions of the world into different water vapor model by latitude and season, see table 1 and table 2.

Latitude (°N)	Jan.	March	May	July	Sept.	Nov.
80	SAW	SAW	SAW	MLW	MLW	SAW
70	SAW	SAW	MLW	MLW	MLW	SAW
60	MLW	MLW	MLW	SAS	SAS	MLW
50	MLW	MLW	SAS	SAS	SAS	SAS
40	SAS	SAS	SAS	MLS	MLS	SAS
30	MLS	MLS	MLS	T	T	MLS
20	T	T	T	T	T	T
10	T	T	T	T	T	T
0	T	T	T	T	T	T

Table 1 the Suitable Water Vapor Model of Different Latitude and Different Seasons in the Northern Hemisphere

Model Atmosphere	Water Vapor (std atm-cm)	Water Vapor (g/cm^2)	Surface Air Temperature
Sub-Arctic Winter(SAW)	518	0.42	-16 ℃ or 3 ℉
Mid-Latitude Winter(MLW)	1060	0.85	-1 ℃ or 30 ℉
U.S.Standard(US)	1762	1.42	15 ℃ or 59 °
Sub-Arctic Sunmer(SAS)	2589	2.08	14 ℃ or 57 °
Mid-Latitude Summer(MLS)	3636	2.92	21 ℃ or 70 °
Tropical	5119	4.11	27 ℃ or 80 °

Table 2 the Specific Parameters of Each Water Vapor Model

When preparing for the parameters of FLAASH feature spectral rebuilding, the paper used DEM data to extract average surface elevation of hyperspectral data in corresponding areas of each scene. In DEM data, we computed DEM data's maximum, minimum and mean value in the way of ROI (region of interest).The mean value is just the corresponding average surface elevation. Then selecting corresponding atmospheric model according to imaging time and latitude /longitude of image center.

The study area is located in between 39°46´N and 40°11´N, 109°58´E and 110°40´E,and the imaging times are Oct.28,2003;Sep.10,2003;Apr.21,2004;May.7,2005,therefore we selected MLS as rebuilding model. Effect image by FLAASH shows in figure 3.

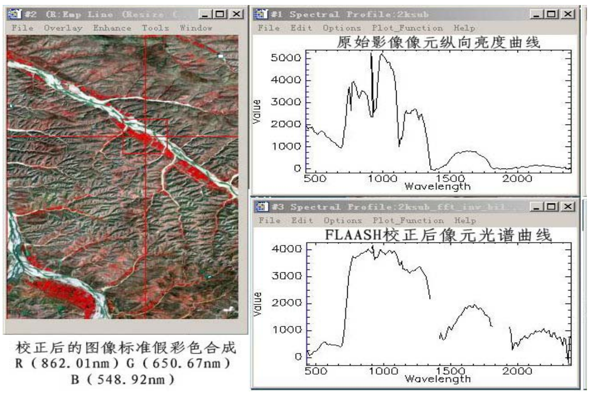

Figure 3 Effect Image by FLAASH (Vegetation Pixel)

5. COMPARISON AND ANALYSIS OF THREE CALIBRATION MODEL

On the basis of Radiation, geometric correction and noise elimination, using the three models to make the reflection rate conversion, and taking vegetation, uncovered rock as examples to extract their reflectance spectra curve respectively (each category features corresponding to three models are both extracted at the same point),see figure 1,figure 2,figure 3,figure4 and figure 5.

From the figures, we can see that the vegetation, uncovered rock spectra curve retrieved by IARR are just relative reflectance among bands, not true feature spectra curve.

Uncovered rock spectra curve retrieved from ELC looks like vegetation curve, the vegetation curve has problem in low-value areas, and it is not consistent with measured curve. But to FLAASH, the vegetation spectra curve is consistent with measured curve no matter in run or trend.

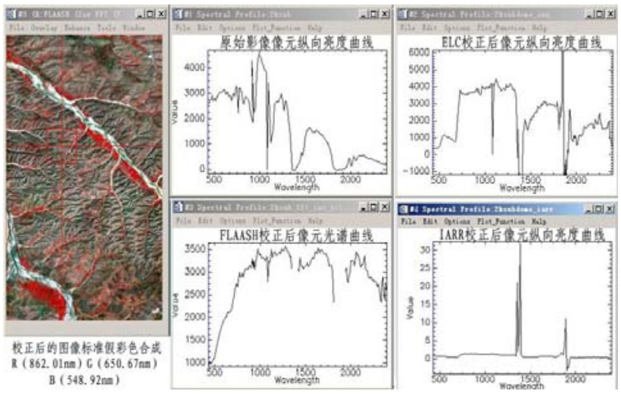

Figure 4 Contrast of Three Correction Methods (uncovered rock pixel)

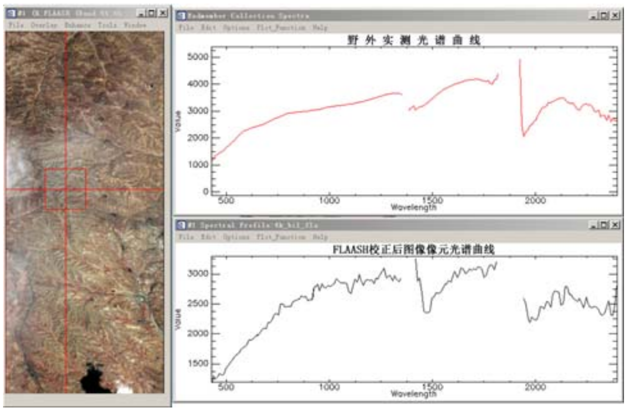

Figure 5 Contrast of Field Measured Spectral Curve and Pixel Spectral Curve

6. THE TRUTH TEST OF SPECTRAL REBUILDING

In the process of spectral rebuilding, it may produce some fake characteristics which will cause image spectrum distortion because of noise, way of dealing and EFFORT process.Hence; it must test and evaluate the authenticity of rectified reconstruction spectrum data.

In general, evaluating image spectrum distortion by comparing the minerals' characteristic spectrum wavelength of image and field which are at the same location.Testing method: Comparing the known point in Hyperion absorption peak wavelength location of known point with characteristic absorption peak of the measured spectral characteristics one by one, analyzing the offset is in a reasonable spectral range or not that in terms of spectral resolution and spectral bandwidth.

This is mainly because ground spectrograph's spectral resolution is several times the imaging hyper-spectrograph. If they are fully consistent in a reasonable spectrum range, the image spectrum represents the spectral characteristics of actual features. If difference is large, it would be needed to re-adjust parameters in order to proceed with serials of radiometric correction.

This text is mainly from the perspective of hyperspectral data's atmospheric correction and truth assessment to elaborate the application of feature spectrum in hyperspectral data preprocessing, emphasizing that the feature spectrum is not only in the application of information extraction and classification.

In the atmospheric correction process, spectrum characteristics of data area's feature distribution and handling to some specified characteristic spectrum in the information extraction will both affect the input of rectified model parameters.

You should understand and master the spectral characteristics of features that come from standard spectral library which participating directly in data correction when using EFFORT model to the fakeness remove or enhancement and also smoothness of image spectral characteristics reconstruction.

There are two ways to check and assess the truth of reconstructed spectral data. On the one hand, we can make comparison analysis and evaluation on the basis of understanding a certain feature's distribution combining with standard spectral library; on the other hand, we can compare and evaluate it directly on the basis of field spectrum measurement to the same image point.

After the atmospheric correction of image data, the most directly evaluation method to judge the correction is good or bad is to assess the water vapor image that produced in atmospheric correction.

See figure 6,generally speaking, if the water vapor is in fog state，it means good correction effect. If the features are visible in the water vapor image, it means bad correction effect, and it needs to be rectified again by resetting parameters.

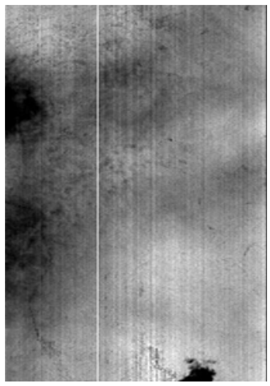

Figure 6 Vapor Water Image Produced by FLAASH with the Fourth Scene of Data

7. CONCLUSIONS

①To the model based on image own identity conversion, the calibration effect is ordinary, and affected by human factor greatly. Same data, choosing different space location pixel value as reference value will get a result as like as chalk and cheese.

②The ELC is simple, easy to be achieved, and it has good reconstruction effect. But it needs synchronous or quasi-synchronous spectrum test when acquiring data and the correction effect depends on the calibration points strongly.

③ The calibration model based on the theory of atmospheric radiation has the best calibration effect.

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