Study on an algorithm for atmospheric correction of Landsat TM imagery using MODTRAN simulation

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Abstract

A technique on atmospheric correction algorithm for a single band (0.76-0.90 μm) reflective of Landsat TM imagery has been developed using a radiation transfer model simulation. It proceeds in two steps: First, calculation of the surface reflectance of each pixel based on precomputed planetary albedo functions for actual atmospheres(e. g. radiosonde) and two kinds of atmospheric visibility states. Second, approximate correction of the adjacency pixel effect by taking into account the average reflectance in an 7 × 7 pixel neighbourhood and using appropriate land cover classification in reflectance. The correction functions are provided by MODTRAN model.

1. Introduction

Atmospheric corrected surface reflectance images improve the accuracy of surface type classification and satellite image analysis, and the ground reflectance data is also important as a basis for estimating land imagery information. Despite the fact that the technique of satellite image processing using new improved software has been continually developed, there is still a difference between the radiance value registered by satellite borne detector and the true value registered at the ground surface due to atmospheric attenuation effects of radiance energy transfer process. Such reflective attenuation of radiance is mostly associated with the presence of aerosol particles in atmospheric suspension and surface irradiance characteristics. The effects of aerosol reflectance is a function of spectral atmospheric optical depth and concentration, and closely related to latitude, geographical location, altitude and local air mass movement. Therefore, when the effects of surface diffuse and aerosol reflectance are eliminated from the satellite image, the image is actually recognized as a atmospheric corrected

image. Similar aspects as discussed above had been also treated by Kaufman(1988) and Richter(1990) to the spectral reflectance over European and Canadian atmospheric background respectively. They could derive an algorithm of atmospheric correction to the solar radiance reflectance but the values were under quasi operational conversions.

This paper describes a simple atmospheric correction algorithm to derive the surface reflectance and surface radiance which is measured by Landsat TM 5 in the visible and near infrared parts of spectrum over rural aerosol condition(23 km of visibility). The procedure is considered with two steps; first the spectral surface reflectance of Landsat TM image are calculated by using a radiation transfer theory in the model of MODTRAN under actual atmospheric conditions. Second the correction function of atmospheric reflectance is to eliminate the diffusion reflectance of atmospheric path and adjacent pixels within each spectral band. MODTRAN is a computer code calculates atmospheric transmittance and atmospheric path radiance. The version is an extension and update of LOWTRAN 7 (1988). When the observed atmospheric soundings are available in the model run, the error in the retrieved surface reflectance will be reduced.

2. Theoretical considerations and methods

The first step of the algorithm is to compare the measured and model-derived planetary albedos for the surface reflectance. The measured planetary albedo ρ_P is related to the digital number(DN) in satellite channel i (Richter, 1990).

$$\rho_P(\text{measurement}) = \frac{\pi L(\lambda_i)d^2}{E_S(\lambda_i)\cos\theta_S} = \frac{\pi d^2}{E_S(\lambda_i)\cos\theta_S}[c_0(i) + c_1(i) \times DN] \qquad (1)$$

where $L(\lambda_i)$ and $E_S(\lambda_i)$ are spectral radiance at satellite sensor and extra- terrestrial solar irradiance. $c_1(i)$ and $c_0(i)$ are offset and slope of calibration coefficients respectively. λ_i is the centre wavelength. θ_S is the solar zenith angle and d is the Earth-Sun distance in astronomical units. MODTRAN first calculates the solar radiance reflected from a uniform Lambert surface reflectance $\rho(\lambda)$ as shown Kaufman in (1985).

$$L(\lambda) = L_0(\lambda) + \frac{E_g(\lambda)}{\pi} \rho(\lambda)[T_{dir}(\lambda) + T_{dif}(\lambda)] \qquad (2)$$

where L_0, E_g, T_{dir}, T_{dif} are path radiance for a black ground $(\rho = 0)$, ground reflected radiance, the direct and diffuse transmittance (ground to sensor) respectively. The path radiance $L_0(\lambda)$ can be obtained by a black surface condition in the model with $\rho = 0$. The term of T_{dir} and T_{dif} can then be evaluated from radiation transfer equation in MODTRAN. The path transmitance, $T_{dif}(\lambda)$ is defined by

$$T_{dif}(\lambda) = \exp(-k_{\nu}u) \tag{3}$$

where u and k_{ν} means the atmospheric path and extinction coefficient respectively. The model-derived planetary albedo $\rho_p(\text{model})$ is calculated with band-integrated terms as

$$\rho_P(\text{model}) = \alpha_0(Atm,\ \theta_V,\ \theta_S,\ \phi) + \alpha_1(Atm,\ \theta_V,\ \theta_S) \times \rho_p \tag{4}$$

$$\alpha_0 = \frac{\pi d^2 \int_{\lambda_1}^{\lambda_2} \Phi(\lambda)L_0(\lambda)d\lambda}{\cos\theta_S \int_{\lambda_1}^{\lambda_2} \Phi(\lambda)E_S(\lambda)d\lambda} \tag{5}$$

$$\alpha_1 = \frac{d^2}{\cos\theta_S} \frac{\int_{\lambda_1}^{\lambda_2} \Phi(\lambda)E_g(\lambda)[T_{dir}(\lambda) + T_{dif}(\lambda)]d\lambda}{\int_{\lambda_1}^{\lambda_2} \Phi(\lambda)E_S(\lambda)d\lambda} \tag{6}$$

where ρ is the averaged surface reflectance in-band, ($\rho \approx \int \rho(\lambda)\Phi(\lambda)d\lambda$). The α_0 and α_1 is a regression coefficients respectively which is a function of atmosphere atm and satellite parameters. θ_V is the sensor view angle, ϕ is the relative azimuth angle and Φ is the normalized spectral response function of the sensor. If the measured planetary albedo agrees with the model-derived value through an iteration process, the algorithm yields the surface reflectance $\rho^{(1)}$ from the atmospheric diffusion effects.

$$\rho^{(1)} = \frac{1}{\alpha_1}\left[\frac{L(\lambda_i)}{E_S(\lambda_i)\cos\theta_S} - \alpha_0\right] \tag{7}$$

The algorithm also computes the average reflectance in an N x N pixel window centered on the considered pixel of satellite image:

$$\bar{\rho}^{(1)} = \frac{1}{N^2} \sum_{j=1}^{N^2} \rho_j^{(1)} \tag{8}$$

The model-derived reflectance $\rho^{(1)}$ of Eq. (7) is based on the Lambertian surface, wheres the satellite planetary albedo actually consists of the direct reflectance ρ at the centered pixel and the diffuse background reflectance $\bar{\rho}^{(1)}$ of the adjacent pixels.

$$L(\lambda) = L_0(\lambda) + \frac{E_g(\lambda)}{\pi}\rho(\lambda)T_{dir}(\lambda) + \frac{E_g(\lambda)}{\pi}\bar{\rho}^{(1)}(\lambda)T_{dif}(\lambda) \tag{9}$$

Comparing Eq. (2), a relation of $\rho^{(1)}(T_{dir}+T_{dif})=\rho T_{dir}+\overline{\rho}^{(1)}T_{dif}$ can approximately be obtained. The final surface corrected reflectance $\rho^{(2)}$ is defined as

$$\rho^{(2)} = \rho^{(1)} + q(\rho^{(1)} - \overline{\rho}^{(1)}) \tag{10}$$

where q is a regression coefficient which is assumedly obtained by a reflectance ratio between the center and adjacent pixels as

$$q = \int_{\lambda 1}^{\lambda 2} \frac{\rho_{p\lambda}(measure)}{\rho_{p\lambda}(model)} \Phi(\lambda)d\lambda \tag{11}$$

The appropriate window size in TM image, N, in Eq. (8) depends on the pixel size, the atmospheric parameters, the spectral band and the spatial frequencies of the scene itself (Kaufman 1985).

3. Assumptions and atmospheric data

Two simplifying assumptions were respectively adapted to the TM image of five surface targets, water, forest, rice paddies, wet-bare soil, urban area, for the algorithm. (1) The relative azimuth angle dependence of the path scattered radiance is neglected for the standard catalogue, because the largest off-nadir angle of Landsat is 7.5° . (2) The surface reflectance Eg is depended on some extent on the surface albedo. (3) Atmospheric data were measured by a radiosonde up to an altitude of 25 km. Atmospheric conditions of the altitude region 25 - 100 km were taken from the LOWTRAN 7 mid-latitude summer atmosphere based on the rural boundary layer aerosol type with 25 km of visibility.

The satellite TM image data of Ansan area (500 × 700 pixel size) on a single date of 20 May, 1993 in this study is very complicate with residential area, forest, rice paddies, ocean and coastal wet-bare soil. The atmospehric sounding data for the model run was adopted to the observations of 9:00 AM at Osan as shown in Table 1.

4. Procedure and Results

The calculation process for $\rho^{(2)}$ in the study is as follows:

(1) calculation of the measured planetary albedo ρ_p of each target in TM 5 image,

(2) determine the Lambercian surface reflectance $\rho(\lambda)$ by using an iteration process in MODTRAN model compare with ρ_p(measurement),

(3) calculation of the ρ_p(model), α_o and α_1 based on $\rho(\lambda)$ as shown in table 1.

(3) detemine $\rho^{(1)}$ and $\overline{\rho}^{(1)}$ using α_o and α_1 , and the final surface reflectance $\rho^{(2)}$ of Eq. (11).

A TM scene of band 4 (0.76-0.90 μm) is only selected for deriving the atmospheric correction algorithm on May 20, 1993 at Ansan area in this study. The algorithm transforms the original radiance image into a reflectance image. The band 4 has a good reflection characteristics to urban, green vegetation, soil moisture and water body.

The algorithm process has two steps: First, for the model atmospheric corrected planetary albedo of Eq. (7), a simple estimation equation was derived from the satellite reflectance of the band and using MODTRAN assuming the standard mid-latitude summer atmosphere with an rural visibility condition. In second step the diffuse reflected radiance of adjacent surface pixels were obtained at the averaged adjacent reflectance of 7 × 7 pixels; i.e. about 200-200 m to either side around the center pixel are available. Since the Ansan scene consist of many small fields of different reflectance, the effective range of the adjacency effect can be reduced to about 100-500 m. Through the elimination of the adjacent diffusion reflectance from the original satellite imagery, the original reflectance in the five targets were enhanced by the correction factor of q as shown in Table 2. This result is similar with Richter's (1990) study the TM imageries at Munich where is surrounded agricultural and forest region with the reflectance of 40 per cent were increased with 6 per cent in the reflectance on the centered pixel. Figure 1 shows the Landsat TM 5 scene of Ansan city with original image and the colored-coded reflectance, and the distribution of adjacent diffusion correction factor, q for the algorithm.

5. Conclusion

A technical method for development of atmospheric correction algorithm for the reflective solar spectrum is presented. The technique is approximately accounted for the adjacency pixel reflective and atmospheric diffusion effects. As shown in Figure 1 we could calculate the atmospheric path radiance and correction factor q, but not yet the error check between this two kind of reflectance.

Finally we are not finished yet the calculation of the corrected reflectance $\rho^{(2)}$ but the values will be easily obtained by using q and the relation between center reflectance obtained from MODTRAN radiative transfer model calculation of the averaged adjacent reflectance and the error limits will be considered in the next work process.

Reference

Richter, R., 1990: A fast atmospheric correction algorithm applied to Landsat TM images. *International J. Remote Sensing,* 11, 159-166.

Kaufman, Y. J., 1985: The atmospheric effect on the separability of field classes measured from satellite. *International J. Remote Sensing,* 18, 21-34.

Kaufman, Y. J., and Sendra, C., 1988: Automatic atmospheric correction. *International J. Remote Sensing,* 9, 1357-1381.
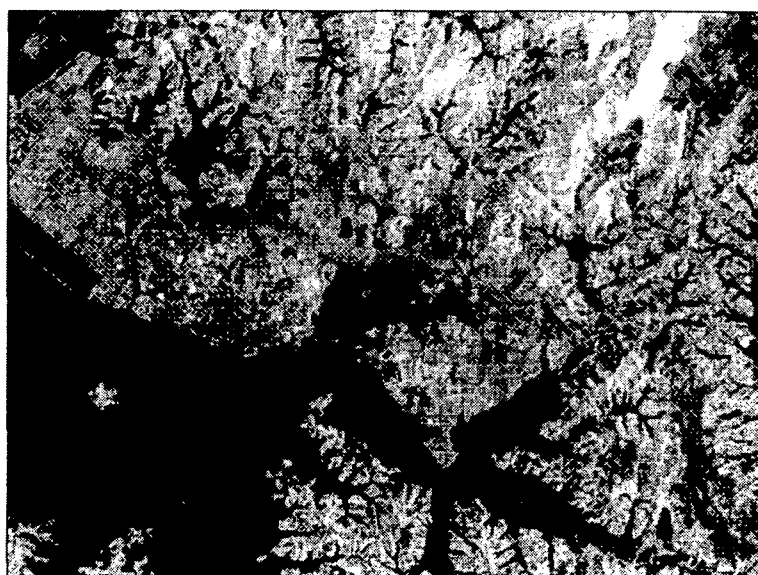
(a)
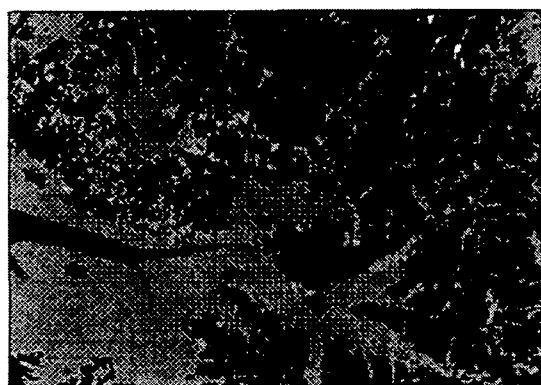
(b)

(c)

Figure 1. Landsat 5 Thematic Mapper scene of Ansan city(May 20, 1993), band 4, 3 and 2. (a) original scene, (b) ground reflectance image and (c) distribution of the atmospheric correction factor q.

Table 1 Input parameters for MODTRAN radiance calculation

parameters	content
Landsat TM band 4	$0.76 \sim 0.90 \, \mu m$
Aerosol Type (visibility)	rural 23km
Solar zenith angle	$30.1°$
Relative azimuth angle	$180°$
atmospheric profile	May 20, 1998, 00UTC Osan
Ozone profile	Pohang - spring profile
L_0 (W/cm^2/sr)	7.32×10^{-5}
E_s (W/cm^2)	1.46×10^{-2}
E_g (W/cm^2)	1.11×10^{-2}
τ	0.76
α_0	0.019
α_1	0.7

Table 2 Calculated surface reflectance of land classified targets

Parameters \ Target	forest	wet land	water	rice paddies	urban area
ρ_p	0.61	0.27	0.21	0.23	0.40
ρ	0.84	0.36	0.27	0.30	0.54
q	0.942	0.989	0.981	0.996	0.987

ρ_p : measured TM reflectance
ρ : corrected surface reflectance derived from ρ_p and MODTRAN
q : correction reflcetance factor for adjacent pixel