A Topographic Correction Approach by Using Spatial Context Information

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Abstract: The topographic correction refers to the compensation of the different solar illuminations due to the irregular shape of the terrain. The effect causes a high variation in the reflectance response for similar vegetation types. Therefore, the process of topographic normalization may be critical in areas of rough terrain, as a preliminary step to the multispectral and multitemporal image classification. The conventional pixel-based topographic correction methods usually overestimate the radiation in low sun incidence angle, although reducing the variation in averages. In this paper, a spatial contextual approach is proposed after analyzing these errors. The experiments using a Landsat TM image and DEM in west of Hubei Province have proved that the results of the contextual method are better than that of the conventional correction methods.

Key Words: topographic correction, spatial contextual, remote sensing.

1. Introduction

Remote sensing of vegetation in rugged areas is severely affected by the topographic effect [1]. The effect will cause great variety of the same vegetation. Therefore, the process of topographic normalization may be critical in areas of rough terrain, as a preliminary step to the multi-spectral and multi-temporal image classification [1] [2].

For decades, the effect of topography on remotely sensed data has been explored by many researchers who have attempted to model and reduce the influence of local terrain slope and aspect with the aim of improving land cover identification [1]. General topographic correction models include the Lambert model and the Minnaert model. Other models are empirical or semi-empirical. Although these models have different accuracy, they usually fit data well and remove most topographic effect [2] [3]. However, it is also observed that these models usually overestimate the radiance for the lower incidence angles of slopes facing away from the sun [2][3][6]. The errors are primarily caused by that the conventional methods are based on signal pixel, ignoring the effect of adjacent terrain [3][8]. Although several methods [6] have compensated the effect resulted from adjacent terrain, the result of the methods are not desirable because of the effect defined as a experiential factor, absenting exact physical explain.

In this paper, a contextual topographic correction method is proposed and tested on a subset of the September 1,1999, Landsat TM image in west of Hubei Province, China. The method is based on the empirical linear relationship between radiance and the cosine of the incidence angle. At the same time, the information in nearby pixels is also used to improve the correction accuracy.

2. Data Preparation

In this paper, region west of Hubei Province (E110º44'33", N30º18'10")in china is primarily tested and researched. The altitude of it is ranging from216 to 2320 meter. The study region is mostly covered with all kinds of forests.

This paper got the Landsat TM (thematic mapper) image. Spatial resolution of TM image is 30 meters and there are 7 bands whose wavelength ranges from 0.45 to 2.35nm covering visible light, near infrared, thermal infrared and short wave infrared. ETM scene acquired in 1999 is used in this study. At the same time, DEM (Digital Elevation Model) is elected and employed as an important factor in correction model. DEM is created by jointing some relief map scaling 1:50000, making DRG Digital Raster Graphic) and digitizing it. Then it was converted into raster data of the same resolution with TM image.

3. Method

3.1 Errors Analysis to Topographic Correction Models

It is obvious that the errors of topographic correction may result from various aspects, such as the resolution and accuracy of DEM. In order to reduce these errors caused by other factors independent with models, the traditional models all take them into account. For example, the DEM should have a better resolution than the satellite scene, but at least the same [5]. Therefore, in this paper, Only errors resulted from topographic correction models are discussed.

The quality of samples in model is considered as one of important factors which affect the results of topographic correction. Therefore, three samples with different qualities are chose in the band 4 of TM image. The factors of the correction model are calculated by the samples respectively, and are used to process the TM image respectively. The quality of the three samples and the correction results by the three samples are showed in table 1. The correlation is a index of the quality of samples. The higher the correlation is, the better the quality of samples is. It is obvious that the means of DN in the band 4 of the TM image caused by the three samples are similar to that in raw image, at the same time; the standard deviations of DN in the band 4 of the TM image caused by the three samples all exceed that of the raw image. And the correlation between std and the quality of sample is indistinct. Consequently, the errors cannot always be significantly reduced by using more accurate models because of complex of remote sensed data in terrain area[4]. The quality of samples isn't a crucial factor to reducing errors, if the errors of the quality of samples are considerable.

Table1. Relationship between result of correction and quality of samples

sample	correlation	mean	std
raw image	——	79.1698	10.8377
No1 sample	0.75166	80.9761	20.2933
No 2 sample	0.84357	74.4222	19.5549
No 3 sample	0.91097	79.0659	24.1334

To further analysis the errors resulted from topographic correction models, the factors of model are calculated respectively in raw forest image and after atmospheric correction. For example, as showed in table 2, in C model, the value of the factor b related to sun incidence angle is invariable and after. Meanwhile, the value of the factor a not related with the incidence angle is smaller than that before atmospheric correction. Therefore, the factor a is considered as a factor related to both atmospheric scatter and terrain scatter[4][6]. The factor a is primarily related to radiance received by adjacent pixels after atmospheric scatter.

Table2. Parameter of model before atmospheric correction and after in C Model

$L = a + b\cos i$		a		b	
		before correction	after correction	before correction	after correction
band	1	43.7835	15.0949	5.39022	5.39022
	2	26.9174	11.5627	13.3158	13.3155
	3	6.8234	5.3000	9.8315	9.8309
	4	32.0980	30.221	59.4242	59.3942
	5	3.1010	3.0024	8.8474	8.8475
	7	0.6544	0.6544	1.0703	1.0703

In band 4 of TM image, the values of factors a b are both bigger than the other bands. It indicates that the radiance of vegetation is more sensitive in infrared band than the other bands, and the radiance of central pixel is affected obviously by adjacent pixels, which are identical to the character of vegetation in infrared band theoretically. However, the factor a only describes the effect of adjacent pixels in the whole scene in general, ignoring the effect to each pixel exactly. On one hand, the effect of adjacent pixels is considered as a constant in model, on the other hand, the radiance of pixels with low incidence angles are variable because of complicated adjacent terrain. It is the contradiction that causes overestimating radiance of pixels with low incidence angles.

With above analysis, we conclude that correction errors are possibly caused by the traditional models based on single pixel without relating to adjacent terrain. Therefore, a new topographic correction method by using spatial context information is proposed in the paper.

3.2 Contextual Topographic Correction Method

Conventionally, the traditional correction models based on the empirical linear correlation between observed radiance L_T and $\cos i$:

$$L_T = a + b\cos i \qquad (1)$$

where, $\cos i$ represents the cosine of the sun incidence angle.

Under the assumption that for the flat pixel:

$$L_H = a + b\cos\theta \qquad (2)$$

where, $\cos\theta$,which normalizes radiance for the flat pixel ,represents the cosine of the sun zenith angle.

The following empirical correction algorithm for vegetation can be derived:

$$L_H = L_T + b(\cos\theta - \cos i) \qquad (3)$$

in Eq.(3), the effect of observed radiance for changes in the direct irradiance is corrected, merely. However, the effect of spatial context isn't ignorable. In the new correction method, the effect isn't considered as a constant, but analyzed exactly for each pixel. So, Eq.(3) can be rewritten as:

$$L_H = L_T + b(\cos\theta - \cos i) - L_{IP} \qquad (4)$$

where, L_{IP} represents the adjacent terrain irradiance from adjacent pixel P to central pixel I . L_{IP} is expressed as[7][9]

$$L_{IP} = \sum_{P=1}^{n} L_P \cos T_P \cos T_I \, dS_I / r_{IP}^2 \qquad (5)$$

where, L_p is the radiance of P , T_P and T_I are the angles between the normal to the ground and the line PI , dS_I is the area of central pixel I , r_{PI} is the distance between P and I . In Eq.(5), the distance r is a decisive parameter the irradiance L_{IP} varies according to $1/r^2$. T_P and T_I are another important parameters, which must include the adjacent pixels that are oriented towards central pixel and not hidden from central pixel[7][8]. However, estimating the adjacent pixels is hidden or not is so complicated that it is difficult to calculate. Considering that only the most adjacent pixels is effective to central pixel, the estimating pixel hidden or not is limited in 3×3pilex. Meanwhile, $\cos T_P \cos T_I$ refers to slope and aspect, which are also included in cosine of sun incidence angle. So, $\cos T_P \cos T_I$ can be replaced by the difference of cosine of sun incidence angles between adjacent pixel and central pixel, Eq.(5) is simplified as

$$L_{IP} = \sum_{P=1}^{n} \frac{w_P L_P \, |\cos P - \cos I| \, dS_I}{r_{PI}^2} \qquad (6)$$

in Eq.(6), the weight w_P is defined as

$$w_P = \begin{cases} 0 & \cos P \le T \\ 1 & \cos P > T \end{cases} \qquad (7)$$

Since the radiance of shaded pixels can be considered that the radiance are all resulted from irradiance of adjacent pixels after atmospheric correction, the radiance of shaded pixels don't represent the true radiance of them. So, the weight w_P is defined to avoid introducing errors caused by shaded pixels into the correction model. In the paper, T is set to 0.05.

Substituting Eq.(6) into Eq.(4) to get

$$L_H = L_T + b(\cos\theta - \cos i) - \sum_{P=1}^{n} \frac{w_P L_P \, |\cos P - \cos I| \, dS_I}{r_{PI}^2} \qquad (8)$$

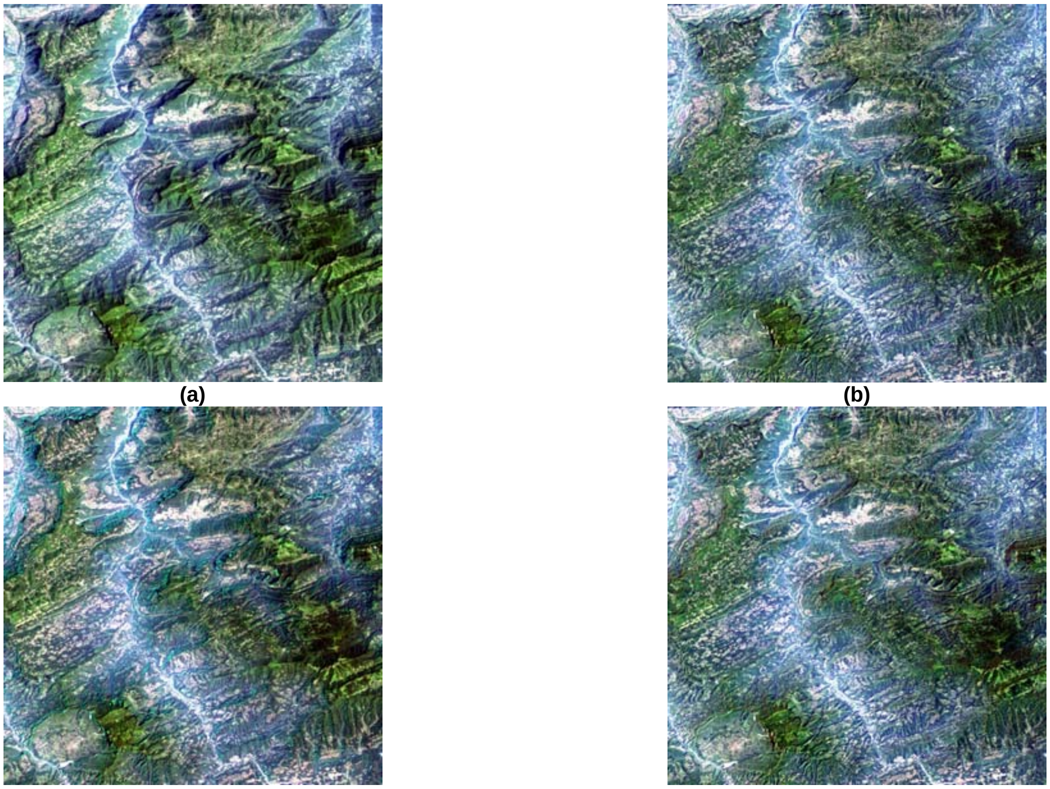
Eq.(8) is the contextual topographic correction model.

4. Application Results

The contextual topographic correction method has been tested on a 756×690pixel subset of a TM image. The widely used Lambert C and Minnaert models were used. Detailed descriptions of these models are provided in references [2].

4.1 Visual Examination

As showed in Fig1, results are obtained for each of the examined TM bands, but for clarity, only result in bands combined band 1,2,3 are displayed. Each method reduces the illumination variety caused by terrain. The result of C Model is similar to that of the contextual method, and the result of Minnaert Model is worst. In table 3, standard deviation of each band after correction is displayed. Although most std are reduced in each correction methods, the result of the contextual method is obviously better than the other methods.



(a) (b)
(c) (d)

Fig.1. TM images (band3,2,1) of the test site: (a) uncorrected, (b) C Model corrected, (c) Minnaert Model corrected, (d) contextually corrected

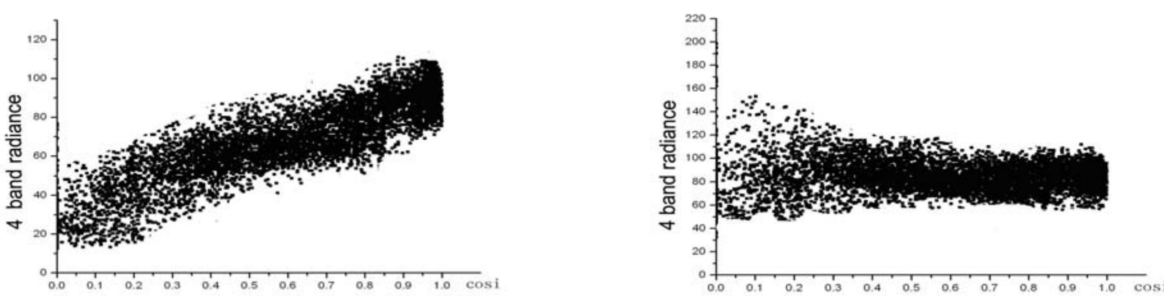
Table3. std in each band before correction and after

band	1	2	3	4	5	7
raw image	4.047	4.888	5.053	16.009	2.616	0.459
C Model	4.557	4.850	4.019	13.084	1.836	0.504
Minnaert Model	4.087	3.016481	5.023	14.537	1.472	0.394
Contextual Model	3.821	3.824	4.232	10.312	1.623	0.391

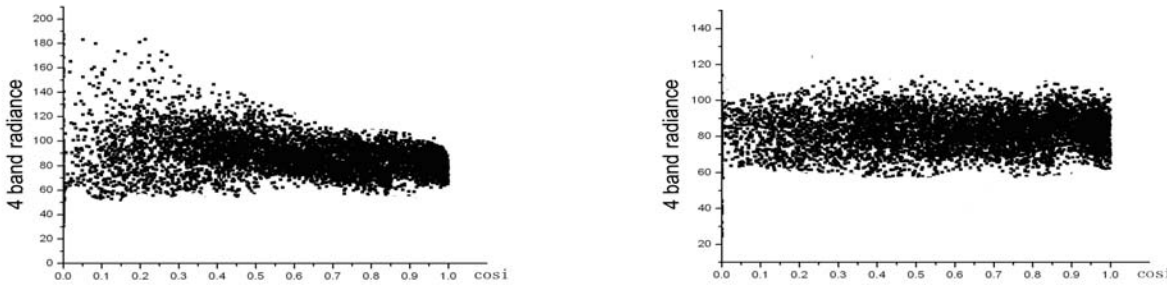
4.2 Radiation Variance Analysis

The correlation between radiance of pixel and cosine of sun incidence angle is a important index to estimate the quality of corrected data[2][10]. It is a positive linear relationship between the radiance and the incidence angle before topographic correction[10]. However, the relationship is removed from data after applying correction.

The relationship between radiance of pixel and sun incidence angle after correction are displayed in Fig2. the result of the three method are all desirable in high incidence angle. However, the radiance estimated with the conventional methods show more scatter in low sun incidence angle ($\cos i < 0.3$). In contrast, the radiance variation in low sun incidence angle has been significantly reduced to the same level as in high sun incidence angle with the contextual method.



(a) (b)



(c) (d)

Fig.2. The correlation between radiance of pixel and cosine of sun incidence angle in 4 band TM image: (a) uncorrected, (b) C Model corrected, (c) Minnaert Model corrected, (d) contextually corrected

In order to further analysis the scatter in low sun incidence angle, the mean-normalized standard deviations have been used to measure the variability of radiance estimated by using different models. As shown in Fig3, each curve depicts the variation of radiance variability with topography. It is obvious that the std is similar to all models in high sun incidence angle, and the std of contextual method is smaller than traditional methods in low sun incidence angle. It indicates that the radiance estimated by the contextual method is more homogeneous and topography independent.

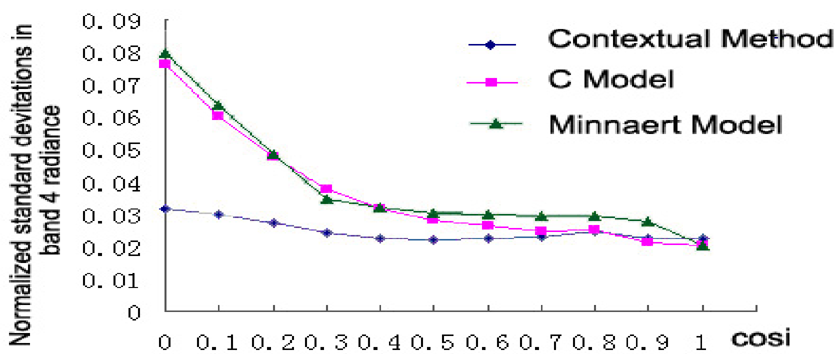


Fig.3. Comparison of variability of radiance estimated with different methods

. 5. Conclusion

From the above analysis, we conclude that the contextual method differs from the conventional, single-based methods primarily in that it remove the effect resulted from adjacent terrain respectively, which possibly to reduce the scatter in low sun incidence angle caused by imperfection of data.

Although only a subset of TM image has been tested by the contextual method, the scene is typical with complicated terrain in forest. It has been proved that the result of contextual method is better than the conventional methods by comparing with several methods

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