ANALYSIS AND CORRECTION TECHNIQUE OF TOPOGRAPHIC EFFECT IN DIGITAL REMOTE SENSING IMAGE

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ABSTRACT

Topographic effect on remote sensed data in hilly and mountainous areas prevents from quantitative analysis, automated classification, scene segmentation and feature extraction of satellite images. The feature and rules of topographic effect on digital remote sensing image are analysed, and the models for topographic effect correction are described in this paper. Mainly the existing models for topographic effect correction are improved and a set of software for topographic effect correction on microcomputer is developed. The satisfactory experiment results of topographic effect correction of TM images are obtained.

Keywords: topographic effect
digital remote sensing image
radiative trsanfer theory
topographic effect correction
digital elevation model (DEM)

The analysis and application of remote sensed imagery, especially, accurate quantitative analysis and application, are mainly based on the spectral signature of objects. However, spectral information of objects in image is subject to disturbance of many factors, e. g. topographic effect, atmospheric influence and etc. The topographic effect is more evident in the hilly and mountainous area. Due to the topographic effect, the terrain elements of same coverage have different irradiance, which reflected in different grey values in image. It seriously affects the image spectral contents, reduces the accuracy of information extraction, leads to misclassification even unclassification, and becames a main obstacle of quantitative remote sensing application.

Investigation of topographic effect in remote sensed images is aimed at reduction of such effect and enhancing the image spectral information. This investigation constitutes an important fundamental topic of quantitative remote sensing application.

1. TOPOGRAPHIC EFFECT ANALYSIS

The topographic effect in digital remote sensing imagery is defined as: a sensor response change of total irradiance of inclined terrain element with respect to the horizontal one, and it is a function of orientation between the iclined terrain element, light source and sensor position (Holben and Justice, 1981). The degree of topographic effect is determined by comparision of irradiance or grey value of the inclined and horizontal terrain elements of the same coverage.

A digital remote sensing image is radiance of a terrain element, detected and recorded by sensor, and is expressed by formula (1).

$$L_\lambda = \rho'(\lambda) \cdot E_\lambda + \Delta\varepsilon(\lambda) \qquad (1)$$

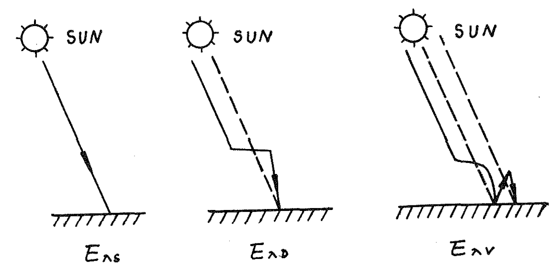
Essentially, the topographic effect in remote sensed imagery is a change of emitted electromagnetic energy caused by topography during transmission. There are two parts included mainly in the formula (1):

(i). $\rho'(\lambda)$—bidirectional reflection factor of terrain element. It expresses the spectral reflection characteristic of terrain features, and depends on the characteristics of the features. $\rho'(\lambda)$ is subject to the topographic influence to some extend, which shall be discussed in the next paragraph.

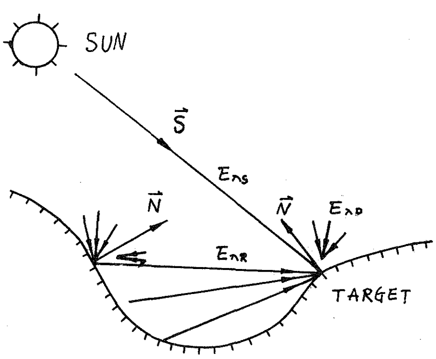
(ii). E_λ — total irradiance of a terrain element. It is a sum of possible irradiances received by the element, and is the main part affected by topography. Topographic effect of E_λ is related to the terrain topography (orientation and environment of terrain element) and characteristics of radiation source. Analysis of topographic effect of E_λ is main concern of the paragraph.

1-1. Flat area

In flat area the total irradiance received by a terrain element (E_λ) can be divided into (Fig. 1-a):



(a). $E_{\lambda}=E_{\lambda S}+E_{\lambda D}+E_{\lambda V}$



(b). $E_{\lambda}=E_{\lambda S}+E_{\lambda D}+E_{\lambda R}$

Figure 1. Components of irradiance received by terrain element

a. $E_{\lambda S}$ — direct solar irradiance,
b. $E_{\lambda D}$ — diffused solar irradiance,
c. $E_{\lambda V}$ — diffused irradiance due to the multiple interactions between terrain and atmosphere. This part is very small and can be neglected.

Thus, all the terrain elements have the same geometry. They have the same effect on the total irradiance (E_{λ}) of terrain element. Therefore, we can say, that digital image in flat area has no topographic effect, and better expresses the spectral characteristics of terrain features.

1-2. Hilly and mountainous area

In hilly and mountainous area, total irradiance received by a terrain element can be divided into (Fig. 1-b):

a. $E_{\lambda S}$ — direct solar irradiance,
b. $E_{\lambda D}$ — diffused solar irradiance,
c. $E_{\lambda R}$ — reflected irradiance from adjacent slopes.

In this case, the terrain elements have a different geometry, thus affect the total irrandiance in various ways. Therefore, there is a topographic effect in digital image of hilly and mountainous area.

1-2-a. Topographic effect of direct solar irradiance

Direct sun light has rigorous orientation. Direct solar irradiance ($E_{\lambda S}$) depends on the orientation and environment of topography in a terrain element.

I. Effect of topographic orientation

The direct solar irradiance ($E_{\lambda S}$) undergoes the influence of topographic orientation of the terrain element, and is a function of solar effective incident angle.

$$E_{\lambda S} = E_{SO} \cdot \cos i\ , \quad \cos i > 0$$
$$E_{\lambda S} = 0, \quad \cos i \leqslant 0 \qquad (2)$$

In the formula, E_{SO} expresses the direct solar irradiance of terrain in the direction perpendicular to the sun light incidence. $E_{\lambda S}=0$ signifies, that the element is in the self-shadow (Fig. 2).

Here, the solar effective incident angle (i) is defined as: an angle between the incident solar light and normal of illuminated element. The formula of caculation is:

$$\cos i = \cos Z \cdot \cos S + \sin Z \cdot \sin S \cdot \cos(\Phi_n - \Phi_s) \qquad (3)$$

In the formula:

cosi — cosine of solar effective incident angle,
Z — solar zenith angle,
Φ_s — solar azimuth angle,
S — slope angle of terrain element, and
Φ_n — azimuth angle of terrain element.

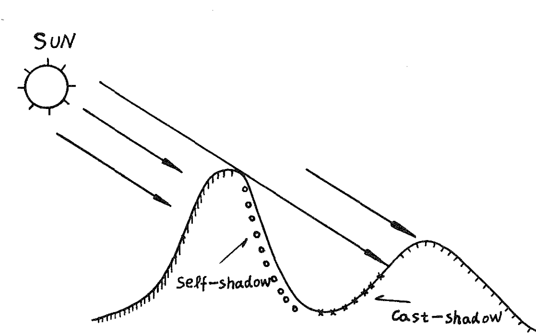


Figure 2. Terrain shadow

II. Effect of topographic environment

The topographic environment effect of direct solar irradiance means, that when a path of direct solar irradiance directed to an element is obstructed by other ones, then the element is falled into a shadow, and can not receive direct solar irradiance, $E_{\lambda S} = 0$. In such case, we say, that the element is in cast -shadow (Fig. 2).

1-2-b. Topographic effect of diffused solar irradiance

Diffused solar radiation is a source of hemisphere, formed from solar radiation, scattered by atmosphere. Diffused solar irradiance ($E_{\lambda D}$) is also subject to influence of the orientation and environment of element topography.

I. Effect of topographic oientation

Distribution of diffused solar radiance is anisotropic and maximum is in the vicinity of solar incident direction[Ref. 9]. The diffused solar irradiance of a terrain element is related to its slope and orientation, usually, it is difficult to determine accurately. Therefore, several simple modles have been deviced for estimation of diffused solar iiradiance [Ref. 10, 9].

II. Effect of topographic environment

Diffused solar radiation source is an one of hemisphere. The effect of topographic environment of diffused solar irradiance means obstruction of irradiance by adjacent slopes, which leads to its reduction(Fig. 3).

Since anisotropy of the diffused solar irradiance , and complexity of topographic environment, so its effect is difficult to determine accurately. Usually, it is assumed, that diffused solar radiation source is isotropic, then its effect of topographic environment is related only with zenith solid angle of the element.

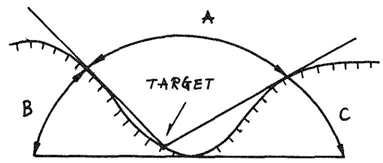


Figure 3. Topographic environment effect of diffused solar irradiance

1-2-c. Reflected irradiance from the adjacent slopes

Reflected iiradiance from the adjacent slopes ($E_{\lambda R}$) means the irradiance reflected from the adjacent slopes received by a terrain element. It is an additional diffused irradiance due to the terrain undulation, and is a specific phenomenon in the hilly and mountainous area (Fig. 1-b).

The study by C. Proy and et al. [Ref. 10, 9] indicates that main factors, on which the reflected irradiance from adjacent slopes of a terrain element is dependent, are trrain reflectivity, environment of adjacent slopes and orientation of the element. Especially, in case of strong terrain undulation and high reflectivity, the snow coverage and vegetation in near-infrared band have shown reflected irradiance from adjacent slopes more remarkable.

1-3. Summary

It is evident from above analysis, that in the hilly and mountainous area the constituting parts of iiradiance of a terrain element are affected seriously by topography, and much more attention should be paid to it. Within them:

(i). Most seriously affected by topography is direct solar iiradiance. It is especially true, when sun elevation is small and terrain undulation is strong. Therefore, the topographic effect of direct solar iiradiance should be eliminated as more as possible.
(ii). The topographic effects of diffused solar irradiance and reflected irradiance from adjacent slopes exist objectively, which deserve consideration while the effects are corrected.

2. TOPOGRAPHIC EFFECT CORRECTION TECHNIQUE

So called topographic effect correction technique means that to transform the irradiances of all the pixels onto a reference plane (usually horizontal plane) , thus to eliminate the changes of grey values (or brightness) in images caused by terrain undulation, to make images better reflect the spectral characteristics of the terrain features. In general, the topographic effect correction is implemented with a help of digital elevation model (DEM).

At present, the topographic effect correction technique includes mainly:

(1). Multispectral band ratio technique;
(2). Technique, based on radiative transfer theory;
(3). Technique, based on image characteristics.

2-1. Multispectral band ratio technique

Multispectral band ratio is a commonly adopted method in digital image enhancement, which is helpful in restraint of multiplicative environment factors in image. Studies have shown, that the topographic effect of direct solar irradiance is a multiplicative environment effect. Therefore, multispectral band ratio has a certain function in restraint of the topographic effect in digital remote sensed images. However, as the topographic effect is not a completely wave length independent multiplicative factor, so the topographic effect behaves to some extend as additive factor. Therefore, a restraint function of multispectral band ratio in digital image is limited [Ref. 5, 9].

2-2. Topographic effect correction, based on the radiative transfer theory

Based on the radiative transfer theory, for a terrain element in flat area, the radiative tranfer equation can be written as:

$$L_{\lambda H} = \rho'(\lambda) \cdot E_{\lambda S} \cdot \cos Z + \rho''(\lambda) \cdot E_{\lambda D} + L_{\lambda P} + \Delta\varepsilon(\lambda) \qquad (4)$$

For a common terrain element, the radiative transfer equation can be written as:

$$L_{\lambda} = \rho'(\lambda) \cdot E_{\lambda S} \cdot \cos i \cdot C_S + \rho''(\lambda) \cdot E_{\lambda D} \cdot C_D + L_{\lambda P} + \Delta\varepsilon(\lambda) \qquad (5)$$

where:
- $L_{\lambda H}$ — radiance of horizontal element,
- L_{λ} — radiance of inclined element,
- $E_{\lambda S}$ — direct solar irradiance,
- $E_{\lambda D}$ — diffused solar irradiance,
- $L_{\lambda P}$ — atmospheric constant,
- C_S — terrain shadow coefficient,
- C_D — topographic correction coefficient of diffused solar irradiance,
- $\rho'(\lambda)$, $\rho''(\lambda)$ — bidirectional reflectance of terrain,
- Z — solar zenith angle,
- i — solar effective incident angle,
- λ — band number.

As assumptions about reflectivity of earth surface are different, therefore, topographic effect correction models based on radiative transfer theory can be divided into two categories: Lambertian model and non-Lambertian model.

2-2-1. Lambertian model

Based on the lambertian reflection hypothesis, the earth surface is an ideal isotropic reflection surface. In such a case, the reflection factor has no relation with terrain, and a following relation exists:

$$\rho'(\lambda) = \rho''(\lambda) = \rho(\lambda) / \pi \qquad (6)$$

where: $\rho(\lambda)$ — hemispheric reflectance.
Then from formulas (4), (5) it results:

$$L_{\lambda H} = \frac{\cos Z + E_{\lambda D}/E_{\lambda S}}{C_S \cdot \cos i + C_D \cdot E_{\lambda D}/E_{\lambda S}} \cdot (L_{\lambda} - L_{\lambda P}) + L_{\lambda P} \qquad (7)$$

In the formula:
- L_{λ} = brightness or grey value of pixel before correction,
- $L_{\lambda H}$ = brightness or grey value of pixel after correction,
- when $i > 90°$, let $\cos i = 0$.

The formula (7) is a topographic effect correction model based on the Lambertian hypothesis. In order to conduct topographic effect correction using formula (7), the following information is needed:

(i). solar angle, i.e. solar zenith angle and solar azimuth angle [Ref. 9];
(ii). topographic factor, i.e. slope angle and azimuth angle of terrain element [Ref. 9];
(iii). atmosperic constants, i. e. $E_{\lambda D}/E_{\lambda S}$ and $L_{\lambda P}$ of different bands [Ref. 1, 9];
(iv). terrain shadow coefficient (C_S) and topographic correction coefficient of diffused solar irradiance (C_D).

The terrain shadow coefficient indicates, that whether the element is fall in shadow. When a terrain element falls in shadow (self- shadow and cast-shadow, Fig. 2), C_S=0, otherwise C_S=1. (About terrain shadow determination see reference [3, 9].)

The topographic correction coefficient of diffused solar irradiance is a ratio of diffused solar irradiance of a common terrain element to the one of horizontal element. The diffused irradiance includes irradiances of diffused solar irradiance by atmosphere and of reflected irradiance from adjacent slopes. In general, diffused irradiance is considered as hemispheric distribution. Thus, multiradiation sources should be considered. The authors propose, that in local area the diffused radiation source is isotropic and of spherical form, therefore,

$$C_D = w / (2 \cdot \pi) \quad (8)$$

where:

w — zenith solid angle, corresponded by a common terrain element [Ref. 9]

For comparison, an often applied correction model which is based on the Lambertian hypothesis, i.e. Teillet model, is given [Ref. 12]:

$$L_{\lambda H} = \frac{\cos Z + E_{\lambda D}/E_{\lambda S}}{\cos i + C'_D \cdot E_{\lambda D}/E_{\lambda S}} \cdot (L_\lambda - L_{\lambda P}) + L_{\lambda P} \quad (9)$$

In the formula:

$C'_D = 1 - S / \pi$,

S — slope angle of terrain element.

Comparing formula (7) with (9), it is clear, that in the Teillet model a correction of cast-shdow point is not considered. the correction coefficient C'_D did not effectively represent the topographic effect of diffused irradiance. There is no distinction between the correction of ridge and vally.

2-2-2. Non-Lambertian model

In fact, reflection of electromagnetic radiation by earth surface is non-Lambertian. the bidirectional reflection factors of terrain element [$\rho'(\lambda)$ or $\rho''(\lambda)$] are related to its topography, and difficult to determine accurately. Minnaert has given an emperical expression for bidirectional reflection factor, so called Minnaert reflection model [Ref. 11, 6].

$$\rho'(\lambda) = \rho(\lambda) \cdot \cos^{K-1} i \cdot \cos^{K-1} e / \pi \quad (10)$$

where:

i — solar effective incident angle,

e — exitance angle, i.e. slope angle of terrain element (nadir pointing sensing),

K — Minnaert constant.

I. Simple non-Lambertian model — Smith model

In view of Minnaert reflection model, Smith and et. al. have proposed a simple topographic effect correction model based on non-Lambertian hypothesis, so called Smith model [Ref. 11]:

$$L_{\lambda H} = L_\lambda \cdot \frac{\cos^K Z \cdot \cos e}{\cos^K i \cdot \cos^K e} \quad (11)$$

II. Modified non-Lambertian model

Smith model is a simple non-Lambertian one, in which the diffused irradiance of earth surface and radiance of atmospheric path are not taking into account. Besides, the model has not given a full consideration to the terrain shadow. Therefore, the authors have proposed a modified non-Lambertian model:

$$L_{\lambda H} = \frac{\cos^K Z + E_{\lambda D}/E_{\lambda S}}{C_S \cdot \cos^K i \cdot \cos^{K-1} e + C_D \cdot E_{\lambda D}/E_{\lambda S}} \cdot (L_\lambda - L_{\lambda P}) + L_{\lambda P} \quad (12)$$

The modified model considers the topographic effect not only of terrain element total irradiance, but also of bidirectional reflection factor of terrain, what means more adequate in theory. However, the constant calculation of the model is still approximate. So a further modification is to be followed [Ref. 9].

2-3. Topographic effect correction models based on image characteristics

The topographic effect correction models, stated above, are based on radiative transfer theory. Regardless of Lambertian models or non-Lambertian ones, all they are built on some hypotheses, i.e. attempting to use a simple mathematic model to describe the complicated remote sensing imaging process. Actually, these hypotheses and models are approximate or not complete. Besides, all the models above stated did not take characteristics of digital remote sensing image itself into account. From above considerations, the paper suggests a topographic effect correction concept based on image characteristics [Ref. 4, 2, 9], and proposed a correction model, in which the image characteristic is considered, and called topographic equalization model:

$$DN'_\lambda = DN_\lambda + DN_\lambda \cdot \frac{Z_O - X}{X_O} \cdot C_\lambda \qquad (13)$$

where:

DN_λ — grey value before correction,
DN'_λ — grey value after correction,
X — cosine of solar effective incident angle (0-255 levels),
Z_O — cosine of solar effective incident angle of horizontal terrain element (0-255 levels),

$$X_O = \begin{cases} X, & \text{when } X > Z_O \\ Z_O, & \text{when } X \leqslant Z_O \end{cases}$$

C_λ — model correction coefficient,
λ — band number.

When the topographic equalization model is applied , first let $C_\lambda = 1$, and coarse correction of original image is carried out in order to get model correction factor. After that, a fine correction of original image is conducted using the refined model.

The model correction factor C_λ is a factor based on image, they are different for different bands. For a specific band, C_λ is related to the magnitude of topographic effect correction of image. C_λ is determied through comparison of original and coarse corrected images [Ref. 2, 9].

The topographic equalization model is essentially a modified cosine correction model, and it takes image characteristic into account . The model is simple in formula and is more practicable.

3. EXPERIMENT AND RESULT ANALYSIS

3-1. Study area

The study area is located in Yongtai county, south-west to Fuzhou, capital city of Fujian province. The area is 4.0×4.5 km^2 , which corrsponds to a patch of TM image of 131× 150 pixels. The elevation is from 50 to 800 m, average slope 20 ° .6 with maximum slope 48° in the area. The area is covered mainly by pine trees, and there are a few paddy field and bush in between.

3-2. Collection of basic data

The image used in the study is TM of Landsat 5 received by Beijing ground station.
WRS: 119 / 42
Receiving time: April 9. 1988
Solar zenith angle: 35 ° 07′ 28″
Solar azimuth angle: 115 ° 44′ 02″

Topographic map 1:50, 000 for control point selection.
Topographic map 1:10, 000 for DEM extraction and vegetation coverage analysis.

3-3. Processing

(i). DEM extraction and matching with image. DEM of study area is extracted from topographic map 1:10,000 manually. Interval of sampling is 30 m. RMSE of matching DEM with image is 0.56 pixels.

(ii). Topographic effect correction. In the expeiment, the topographic effect correction of TM image (bands 1, 2, 3, 4, 5, 7) was carried out by using five different models respectively.

(iii). Software design. A package for topographic effect correction in digital remote sensed image was writen using Fortran 77 on PC.

3-4. Result analysis

In order to compare the effectiveness of different correction models, in table 1 the grey values RMSE of main features (pine trees) of original TM and corrected image in study area are given. From the table 1 it can be seen:

(i). Teillet model has a certain overcorrection phenomenon;

(ii). Modified Lambertian and Smith models have better restraint on topographic effect, but no stable and depend on spectral band;

(iii). Modified non-Lambertian and topographic equalization models correct the topographic effect more adequate and have better stability than others.

3-5. Conclusions

Through the investigation, the following

Table 1. RMSE of grey value of main features (pine trees)   n=4623 pixels

Band	Original	Model A	Model B	Model C	Model D	Model E
TM1	2.29	9.37	5.62	4.05 (K=0.15)	1.85 (K=0.30)	2.09
2	1.80	2.23	1.71	1.77 (K=0.15)	1.57 (K=0.60)	1.52
3	2.46	2.83	2.32	2.29 (K=0.20)	2.21 (K=0.35)	2.20
4	10.47	8.87	7.95	7.20 (K=0.40)	7.94 (K=0.95)	7.37
5	2.62	27.05	18.06	5.47 (K=0.15)	2.52 (K=0.30)	2.08
7	4.39	5.30	4.33	3.35 (K=0.40)	3.50 (K=0.55)	3.48

where: Model A — Teillet model, Model B — modified Lambertian model,
Model C — Smith model, Model D — modified non-Lambertian model,
Model E — topographic equalization model, K — Minnaert costant.

conclusions can be drawn:

(i). The due attention should be paid to the topographic effect in digital remote sensing image in hilly and mountainous area.
(ii). The topographic effect in digital image could be adequately restrained with help of DEM and appropriate correction model.
(iii). Effectiveness of topographic correction depends on many factors, within them the accuracies of DEM and of its matching with image are most important.

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