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원격탐사자료의 放射값 補正

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Radiometric Corrections of Digital Remote Sensing Data

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요 약

원격탐사자료의 픽셀값 變異 중 (위성에 의하여) 走査되는 물체 또는 全景등의 자체에 의한 것이 아닌 기타 변이에 대해서는 픽셀의 방사값을 보정하게 된다. 이러한 픽셀값 변이의 원인에 대해서는 감지장치의 성능차이 및 작동불량, 또는 대기에 의한 간섭효과 등을 들 수 있다. 감지장치들의 성능차에 의하여 (원치 않는) 줄이 그어진 화상자료를, 그리고 작동불량으로 값이 零인 픽셀들을 얻게 되며, 또는 빛의 散亂에 기인하는 대기의 偏倚등이 발생하게 되는 데, 이러한 변이들에 대하여는 그 방사값을 보정한다. 本稿에서는 이러한 방사값 보정법으로 일부 주요원칙에 대하여 예제와 함께 고찰하였다.

Abstract

Radiometric correction refers to variations in the data that are not caused by the object or scene being scanned. These variations can be caused by differing sensitivities of the detectors of the sensing system, malfunctioning detectors, or atmospheric interference. Radiometric corrections can be applied to correct for these variations, such as for differing sensitivities of detectors (causing striped images), for detector malfunctions (resulting in pixels with digital values of zero), or to correct for atmospheric bias due to scattering of radiation. This paper discussed and illustrated some of the important principles of the radiometric correction methods.

Introduction

The ideal or perfect remote sensing system has yet to be developed (Jensen, 1986). Also, the terrain is amazingly complex and does not lend itself well to being recorded by relatively simplistic remote sensing devices that have constraints such as spatial, spectral, temporal, and radiometric resolution. Consequently, error creeps into the data acquisition process and can degrade the quality of the remote sensor data collected. These errors may have an impact on the accuracy of subsequent human or machine-assisted image analysis. Therefore, it is usually necessary to preprocess the remotely sensed data prior to analyzing it in order to remove some of these errors. The methods and formulas that can be used are too varied to be discussed here. Although there are far too many radiometric correction methods to discuss in detail, illustrations of some of the principles important follow.

Detector Errors

In most digital remote sensors, each detector senses radiance along one line (Verbyla, 1992). For example, Landsat Thematic Mapper (TM) has sixteen detectors for each band. These detectors produce a sixteen-line portion of an image with each scan (Fig. 1). However, sometimes a detector fails to function and therefore digital values of zero are recorded and the line on the image appears black. This condition is often called a line dropout, and is illustrated in Fig. 2.

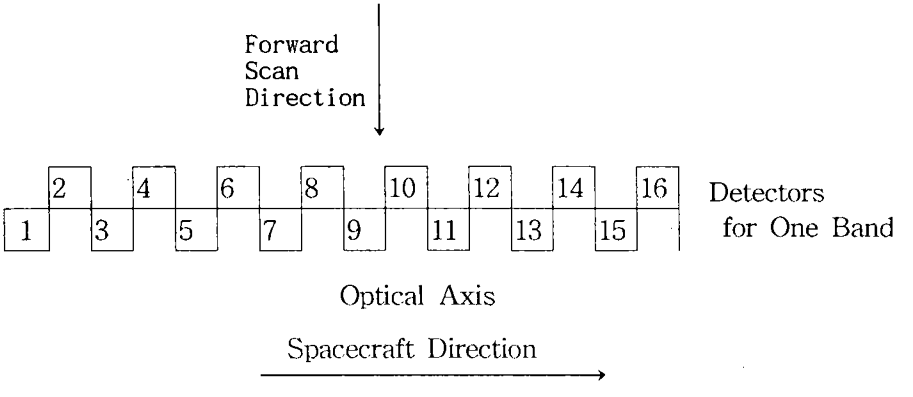

Figure 1. Landsat Thematic Mapper Detector System.

Line dropout is usually corrected by computing the mean of the pixels above and below each bad pixel (Fig. 2). This approach improves the visual appearance of the image. However, it should be aware that the data in the corrected scan line are manufactured from surrounding scan lines, and are not data that were recorded by the satellite sensor.

Before Radiometric Correction:

88	89	84	85	
87	88	81	83	
0	0	0	0	
84	83	79	79	

⇒

After Radiometric Correction:

88	89	84	85	
87	88	81	83	
86	86	80	81	
84	83	79	79	

Figure 2. Line Dropout Due to Bad Detector #3.

Destriping

A systematic banding or striping pattern can sometimes be found on Landsat 1, 2, and 3 Multispectral Scanner (MSS) images (Verbyla, 1992). This striping pattern occurs when an individual detector's radiometric response drifts from its initial (prelaunch calibration) setting. For instance, each Landsat MSS band has six detectors. If one of the detectors (let's say detector #3, as an example) becomes less sensitive to incoming radiance, the digital numbers along that scan line will be consistently less than those from the other five detectors. The image would then appear to have darker stripes at lines 3, 9, 15, 21, and so on.

Destriping procedures generally produce a histogram from scan lines corresponding to each detector. For example, we could generate a histogram for detector #1 by using the digital values from lines 1, 7, 13, etc. We could do the same to generate a histogram for detector #2 using digital values from lines 2, 8, 14, etc. After we have generated a histogram corresponding to each of the six detectors, the histograms could be used to determine unusual detector responses. Correction of digital values from the unusual detector response could then be accomplished by determining an appropriate value to shift the histogram to match the average histogram from the normal detectors (Ahern et al., 1987).

Many natural resource agencies have used satellite data successfully without significant radiometric preprocessing. However, radiometric corrections are critical for applications over large areas, when images from different dates are to be used, or when the results are to be extended to other areas (Clark et al., 1983) or to be compared with those of other sensor data. If we were, for instance, mapping rangeland vegetation using two satellite scenes from different dates, we might expect pixels with vegetation type to have similar digital values. Yet they probably would have different values due to differences in sun angle and atmospheric conditions between the two scenes. The importance of radiometric corrections will certainly increase as researchers attempt to monitor global environmental changes using satellite data (Ahern et al., 1987). These corrections include calibration for direct comparison of different sensors (that is, for using SPOT, Landsat TM and AVHRR for global vegetation monitoring (Price, 1987)), corrections for illumination changes (for example, for direct comparison of satellite data taken on March 21 with that from August 15), and corrections for atmospheric effects. The most common approaches for these corrections are the corrections for sun-angle and atmospheric effects, and will be considered in the following sections.

Sun-Angle Correction

If images generated during different times of the year are to be used for mosaics or compared for change detection, the seasonal effects of variations in solar illumination angle should be normalized (Avery and Berlin, 1992). Corrections can be made by dividing the digital values for each pixel by the cosine of the illumination angle. Scene brightness for each image, regardless of season, is normalized to a solar-illumination angle of 90° Because the function assumes a smooth, flat surface, topographic shadows are retained.

Correction for Atmospheric Effects

Since satellite data are recorded hundreds of miles from the earth's surface, particulate (aerosols) and gases in the atmosphere can scatter, absorb, and refract radiation as it travels the path from the earth's surface to the sensor (Verbyla, 1992). The most dominant atmospheric effect on digital images is usually scattering of radiation, especially in visible wavelengths (Chavez, 1988). Atmospheric scattering of radiation can cause a reduction in image contrast since scattering increases the amount of radiance received by a sensor. Spanner et al. (1990) found that, for Landsat TM band-3 (TM3), approximately fifty percent of total forest stand radiance was due to atmospheric path radiance (mainly due to atmospheric scattering). The reduction in image contrast due to atmospheric scattering is often termed a haze effect. Corrections to adjust for this additive bias to the digital values are often termed dehazing techniques.

The effects of the atmosphere upon remotely-sensed data can be considered not "errors", since they are part of the signal received by the sensing device (ERDAS, 1991). However, it is often important to remove atmospheric effects, especially for scene matching and change detection analysis.

The methods for correcting for atmospheric effects are varied, and depend greatly upon the condition of the data. Several different atmospheric scattering or "haze" removal techniques have been developed. In general, these techniques can be grouped into three categories: (1) methods using complex atmospheric transmission models requiring field or atmospheric information taken during the time of satellite overflight (Forster, 1984; Spanner et al., 1990), (2) methods that estimate the effect of atmospheric scattering using the image data (Crist, 1984; Chavez, 1988; Rice and Odenweller, 1990; Lavreau, 1991), and (3) methods that use images from two or more dates for atmospheric corrections (Caselles and Lopez Garcia, 1989).

The simplest approach for adjusting image data due to the additive bias from atmospheric scattering is often called the histogram adjustment technique (Chavez, 1988). The basic assumption is that there is a high probability that at least a few pixels in a satellite scene should have digital values of zero. This assumption is made because of the great number of pixels in any one scene (for example, an MSS full scene contains over 7,000,000 pixels and a TM full scene contains over 41,000,000 pixels). Therefore there is usually some shadow areas (due to topography or clouds) in the image where the digital values should be zero. However, the digital values in these areas may indeed not be zero because of atmospheric scattering effects. That is, if the digital values in dark, shaded areas of a scene were 10, we would assume that this was due to the atmospheric scattering and all digital numbers in this particular band should be adjusted by -10. The method is called the histogram adjustment technique because it shifts the histogram of digital numbers by a contrast which is assumed to be the additive bias due to atmospheric scattering (Fig. 3).

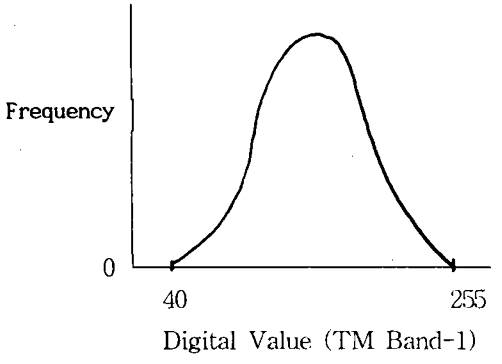

Figure 3. Lower End of Histogram from a Landsat TM Band-1 Scene. All digital values in this band would be adjusted by -40. The value of 40 is assumed to be due to atmospheric scattering as an additive bias to each digital value (Chavez, 1988).

The histogram adjustment technique is simple but has two potential problems: (1) If histograms from a small study area (rather than a full scene) are used, a real minimum digital value may not be present, such as for deep-clear water or dark, shaded areas. Therefore the minimum digital value selected would overcorrect for atmospheric haze. (2) The method may cause some digital values to be over-corrected in some bands and under-corrected in other bands. If this occurs, the spectral relationships between bands may be distorted. Chavez (1988) has developed an improved dark-object subtraction technique for atmospheric scattering correction as follows.

Typically there is an approximately linear relationship between the radiation a detector receives and the output signal from the detector. The slope of this linear relationship is called the *sensor gain* (Fig. 4).

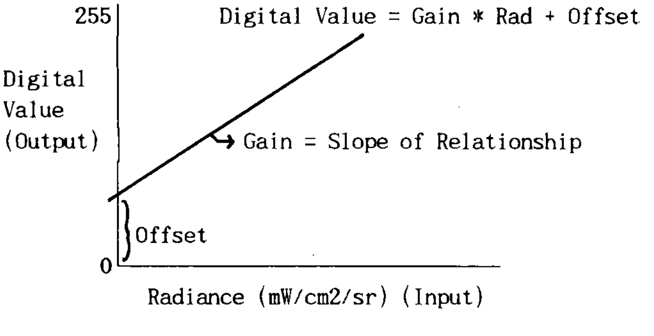

Figure 4. Idealized Prelaunch Radiometric Response of a Detector.

Sensor detectors will give a small signal out (due to residual system noise) even when no incoming radiation is present. This is commonly termed the *detector offset.* The gain and offset values are published for most sensors including Landsat MSS, Landsat TM (Markham and Barker, 1985), and Advanced Very High Resolution Radiometer (AVHRR) sensors (Abel, 1990). Tab. 1 can be referred to for the prelaunch gain and offset values of Landsat-4 TM data.

Table 1. Prelaunch Gain and Offset Values for Landsat-4 Thematic Mapper (Chavez, 1988)*

TM Band (TMx)	Gain	Offset	Normalized Gains (TMx / TM1)
1	15.78	2.58	1.00
2	8.10	2.44	0.51
3	10.62	1.58	0.67
4	10.90	1.91	0.69
5	77.24	3.02	4.89
7	147.12	2.41	9.32

* Actual gain and offset values for a TM scene can be obtained from the header information that is available on the same tape as the satellite scene.

A digital number can be related to actual radiance using the following linear relationship:

$$\text{Digital Number} = \text{Gain} * \text{Rad} + \text{Offset} \quad (1)$$

The amount of radiance a detector receives depends upon several major factors, including the reflectance of the area within the pixel, the slope conditions within the pixel, and the sun elevation at the time of imaging. These factors are multiplicative as components of radiance and will be simplified by a term called *Mult.* Another dominant term that contributes to the amount of radiance a detector receives can be called *Haze.*

Haze contributes in radiance in an additive fashion, therefore we can express Rad as follows:

$$\text{Rad} = \text{Mult} + \text{Haze} \quad (2)$$

Since reflection is assumed to be zero in at least a few pixels of a satellite scene, Mult is assumed to be zero and the expression for radiance can be simplified for those pixels:

Rad = Haze (3)

Combining equations (1) and (3) gives the following expression:

Digital Number = Normalized Gain * Haze + Offset (4)

Atmospheric scattering or haze varies depending upon the spectral region and atmospheric conditions. For example, under very clear sky conditions, the TM1 is affected much more by atmospheric scattering when compared with TM3. This is because, under very clear sky conditions, a type of scattering called *Raleigh scattering* dominates; this scattering is caused mostly by extremely small gas particles that are much smaller than visible wavelengths. The Raleigh model states that relative scattering is inversely proportional to the fourth power of the wavelength. Therefore spectral bands from short wavelength regions (such as TM1) will be affected much more by Raleigh scattering than spectral bands from longer wavelength regions. This is why the sky appears blue: the short blue wavelengths are being scattered much more relative to the longer visible wavelengths (Lillesand and Kiefer, 1987). Under very hazy conditions there are large particulate such as dust and smoke that are about the same size as visible wavelengths. Under these conditions, the *Mie* model of relative scattering predominates. The Mie model states that scattering is inversely proportional to the wavelength. Therefore under these conditions the spectral bands may be effected in a similar manner from Mie scattering. The bottom line is that atmospheric scattering is wavelength dependent and also dependent upon atmospheric conditions. Chavez (1988) developed the following table using the Raleigh and Mie scattering models:

Table 2. Multiplication Factors to Predict Haze Values in Other Spectral Bands Given a Starting Haze Value from the Dark Pixels Within a Landsat-4 TM Scene (Chavez, 1988)

	Atmospheric Condition*				
Spectral Bands	Very Clear (<=55)	Clear (56-75)	Moderate (76-95)	Hazy (96-115)	Very Hazy (>115)
TM1= Starting Haze Value	1.000	1.000	1.000	1.000	1.000
TM2	0.563	0.750	0.866	0.905	0.930
TM3	0.292	0.540	0.735	0.807	0.857
TM4	0.117	0.342	0.584	0.687	0.765

* The digital number ranges (<=55, 56-75, ..., >115) are TM1 histogram haze values that can be used as a guide to selecting suitable atmospheric condition values.

Let's assume that we have a Landsat-4 TM scene with band-1 histogram like Fig. 3. From the histogram, we would select the digital value of 40 as a starting haze value. This could be used in the histogram adjustment technique; however, if we did use this method, the spectral relations among bands might be significantly altered.

We could also use Chavez's (1988) improved dark-object subtraction technique which aims at preserving spectral relationships among bands. The first step in this method is to calculate a reference haze value as the lower digital value from the histogram minus the detector offset value. In this example, we would compute:

Haze Value (TM1) = 40 - 2.58 = 37.42

Assuming the atmospheric conditions were very clear during the satellite overpass, we could use then the values from Tab. 2 to compute the starting haze values for the other bands:

Starting Haze Value (TM2) = 0.563 * 37.42 = 21.1
Starting Haze Value (TM3) = 0.292 * 37.42 = 10.9
Starting Haze Value (TM4) = 0.117 * 37.42 = 4.4

The final haze values can be computed using equation (4):

TM2 Haze Value = 0.51 * 21.1 + 2.44 = 13.2 rounded to 13
TM3 Haze Value = 0.67 * 10.9 + 1.58 = 8.9 rounded to 9
TM4 Haze Value = 0.69 * 4.4 + 1.91 = 4.9 rounded to 5

These values would then be assumed to represent the additive bias due to haze. Therefore these values would be subtracted from the original digital numbers in the satellite scene. Chavez(1989) found that the improved dark object subtraction technique produced similar haze values when compared with sky radiance measured using a radiometer.

Atmospheric scattering is mainly a problem in the visible wavelengths. The amount of atmospheric scattering that occurs in the middle infrared region (TM bands 5 and 7) is very small and except for extremely hazy conditions can be considered negligible.

Radiometric Rectification

A common radiometric response is required for quantitative analysis of multiple satellite images of a scene acquired on different dates with different sensors. Quantitative studies using retrospective satellite data present considerable difficulties (Hall et al., 1991). In such studies it is necessary to account for the effects of atmosphere, illumination, and sensor differences between acquisitions. A considerable amount of research over the past twenty five years has addressed the problem of correcting images for atmospheric differences between dates. These efforts have resulted in a number of atmospheric radiative transfer models that can provide realistic estimates of the effects of atmospheric scattering and attenuation on satellite imagery (Dave, 1978; Kaufman, 1988; Tanrè et al., 1990). However, the application of these models to a specific scene and time requires a knowledge of the sensor calibration parameters and the atmospheric properties: the vertical profiles of atmospheric water vapor, aerosols, and molecular composition at the time. Atmospheric properties may be difficult to acquire even when planned, and are available for almost none of the historical satellite images. Given that this kind of data is not always available for a particular study area, it has been more common in the past to attempt to standardize one data set to another rather than to try and apply the complex modelling that is required to correct for variations in atmospheric transmission and path radiance (Milne, 1988).

The "radiometric rectification" technique (Hall et al., 1991) was used by Choung and Ulliman (1992) for the wetland change detection study to radiometrically rectify the 1985 subject image to the 1988 reference image of Landsat-5 TM. This correction procedure is relatively simple and useful when reliable atmospheric optical depth data or calibration coefficients are not available (Choung et al., 1995). Radiometric rectification corrects images from a common sense in a relative, rather than an absolute sense. Images are rectified relative to a selected reference image. The digital count values from all images so rectified should appear to have been acquired with the reference image sensor, under atmospheric and illumination conditions equal to those in the reference image. All images may be corrected to absolute surface reflectance by using radiometric rectification in conjunction with sensor calibration data and an atmospheric correction algorithm with atmospheric turbidity data acquired for the reference image. Used in this way, atmospheric turbidity data acquired concurrent with any satellite image may be used to infer absolute surface reflectance from any other, historic or future, satellite image rectified to it.

There are two major components in this radiometric rectification algorithm:

(1) One component forms radiometric control sets that have little or no variation in their mean surface reflectance between images such as deep-clear water, dry concrete, bare soil, etc. The members of these sets are not necessarily the same pixels from image to image.

(2) The second component radiometrically rectifies the images using a linear transformation with coefficients calculated to equate the individual band means (in raw digital counts) of the radiometric control sets in each image.

The band-by-band average digital count values of the radiometric control sets are used to compute the coefficients of linear transformations relating all digital count values band by band between the two images (Fig. 5).

Calculation of Radiometric Transform

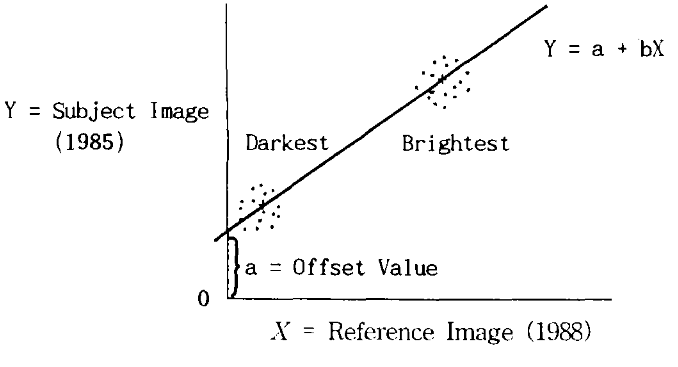

Figure 5. Rectification Transform Approach: Coefficients of the radiometric rectification transforms are the slope and offset of the line connecting the means of the darkest and the brightest radiometric control sets in each band (Choung, 1992).

Simultaneous solution results in:

$$b_i \text{ (slope)} = \frac{B_{Ri} - D_{Ri}}{B_{Si} - D_{Si}},$$

$$a_i\ (\text{offset}) = \frac{D_{Ri}B_{Si} - D_{Si}B_{Ri}}{B_{Si} - D_{Si}}$$

where D_{Si}, D_{Ri}, B_{Si}, and B_{Ri} are, respectively, the means of the darkest (D) and the brightest (B) radiometric control sets in the ith band of the untransformed subject image (S) and the reference image (R). Each ten pixels were selected for the brightest and the darkest control sets in each band for the two data sets, and the results of the rectification in terms of the slope and offset, b_i and a_i, are given in Tab. 3 (Choung, 1992).

Table 3. Rectification Transform Coefficients of Landsat-5 TM Data Between 15 August 1985 and 23 August 1988

	Band-1	Band-2	Band-3	Band-4	Band-5	Band-7
b (Slope)	1.06	1.16	1.15	1.17	1.02	1.02
a (Offset)	4.84	-3.54	-2.04	-4.62	-0.00	-0.31
	(5)	(-4)	(-2)	(-5)	(0)	(0)

The offset value in the parenthesis was subtracted from each digital value in the respective bands of the 1985 subject image to radiometrically rectify to the 1988 reference image (Choung, 1992). However, it was not necessary to adjust the two mid-infrared bands 5 and 7 for atmospheric effects because they originally had offset values of zero.

From the tests of this approach, Hall et al. (1991) concluded that radiometric rectification performed well, removing the effects of relative atmospheric differences to within one percent absolute reflectance.

Summary and Discussion

It is important to recognize that many of the preprocessing operations used today have been introduced into the field of remote sensing from the related fields of pattern recognition and image processing (Campbell, 1987). In such disciplines, the emphasis is usually upon detection or recognition of objects as portrayed on digital images. In this context, the digital values have much different significance than they do in remote sensing. Often, the analysis requires recognition simply of contrasts between different objects, or the study of objects against their backgrounds, detection of edges, and reconstruction of shapes from the configuration of edges and lines. Digital values can be manipulated freely to change image geometry or to enhance images without concern that their fundamental information content will be altered.

However, in remote sensing we are usually concerned with much more subtle variations in digital values, and are concerned when preprocessing operations alter the digital values. Such changes may alter spectral signatures, contrasts between categories, or variances and covariances of spectral bands.

Preprocessing changes data. We assume that such changes are beneficial, but the analyst should remember that preprocessing may influence results of primary analyses in ways that are not immediately obvious. As a result, the analyst should tailor preprocessing to the data at hand and the needs of a specific project and then should use only those preprocessing operations essential to achieve a given purpose.

Because atmospheric scattering is wavelength-dependent and varies with time, obtaining haze-free values is extremely important for spectral ratio analysis and normalizing multitemporal images (Avery and Berlin, 1992). If data base images, excluding TM natural color images, are to be used only for visual interpretations, atmospheric correction is not needed because bias subtraction is accomplished when the digital number data are enhanced by contrast stretching.

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