Least Square Technique for Haze Modeling with 8-Band images

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Abstract

DigitalGlobe launched 8-band challenge among worldwide researchers in remote sensing to employ the capabilities of the new sensor WorldView-2 (WV2) with its 8-bands in achieving more spatial information from the increase in the spectral accuracy. This research tackles the conversion of the Digital Number (DN) of each band into its reflectance value, including an image-based atmospheric correction based on Dark Object Subtraction (DOS). The relation between the 8-bands and atmospheric conditions is analyzed, and a methodology is proposed to model the relative atmospheric model from 8-band data.

Keywords:

Atmospheric correction; 8-band radiance; 8-band reflectance, Kuwait.

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Introduction

The manipulation of remotely sensed data from satellite sensors requires converting sensor output (digital number, DN) to values independent of atmospheric conditions which are values of surface reflectance. The exact estimation of atmospheric parameters is based on radiative transfer code (RTC) to compute the relationship between surface reflectance and radiance at the sensor by measuring atmospheric optical depth at the time of the satellite overpass. This procedure has proven to be accurate, but time consuming and expensive (Holm, et al. 1989).

Table 1 Relative Scattering Model (Chavez 1988)

i	x	Atmospheric Condition	Relative Scattering Model
1	-4	Very clear	λ^{-4}
2	-3	Clear	λ^{-2}
3	-2	Moderate	λ^{-1}
4	-0.7	Haze	$\lambda^{-0.7}$
5	-0.5	Very Haze	$\lambda^{-0.5}$

Several simple procedures for atmospheric correction based on satellite images only were introduced among them the dark-object subtraction (DOS) method (Moran, et al. 1992). The DOS method was improved by COST method which estimates approximate values for atmospheric transmittance (Chavez 1996). Chavez presented a set of five relative scattering models for haze (Chavez 1988), which depend on atmospheric conditions. These models are mainly dependent on wavelength as shown in Table 1. However, the determination of which model to adopt is not described.

In Table 1, (i) is the model identifier, (x) is the exponent value of the model, and (λ) is the mean wavelength of the band. The real scattering model for clear atmospheric condition follows the model of λ^x where (x) varies from (x = -2) for clear to (x = -0.7) for haze condition, as general condition ($-4 < x_i < -0.5$). The value of (x) is determined according to atmospheric conditions during image acquisition.

The aim of this research is to determine the most suitable value of (x) for 8-band images based on the improved method COST for DOS introduced by Chavez (Chavez 1988).

Area of Study

The study area in this research is the Ras Al-Agouza. It exists at the North East corner of Kuwait main land at the entrance of the Kuwaiti Lagoon, centered with the famous Kuwait towers. The study area is approximately a square with 10KM side length, and the data collection date was 16 Feb 2010. The Sensor WorldView-2 (WV2), launched October 2009, is the first high-resolution 8-band multispectral commercial satellite. The received data are shown in Figure 1. The WV2 images are delivered in DN values, and they have to be converted to top of atmosphere radiance before performing any process, in order to maintain same physical reference values and units along all different bands (DigitalGlobe 2009). The conversion from DN to radiance is straight forward, and it needs to be computed by the equation (1) for all 8-bands and pan. The parameters are provided in the "*.imd" file delivered with images.

L[band] = DN * absCalFactor[band] / effectiveBandwidth[band] [W/m^2-ster-µm] (1)

(DigitalGlobe 2009). Each scene in each band has its own absCalFactor value.

WV2 provides also formulae for computing the reflectance at the sensor (Top of Atmosphere), it includes computing solar geometry, Earth-Sun distance, solar zenith angle.

In order to compute the reflectance at the earth's surface, atmospheric correction has to be applied to the images. Since no measurements of atmospheric parameters were observed during image acquisition, the relative atmospheric correction will be applied to the image data.

Table 2 Wavelength values of Worldview-2 sensor

Band Name	Band ID	Band width [nm]
Coastal	1	400 - 450
Blue	2	450 - 510
Green	3	510 - 580
Yellow	4	585 - 625
Red	5	630 - 690
Red Edge	6	705 - 745
NIR1	7	770 - 895
NIR2	8	860 - 1040
Panchromatic	Pan	450 - 800

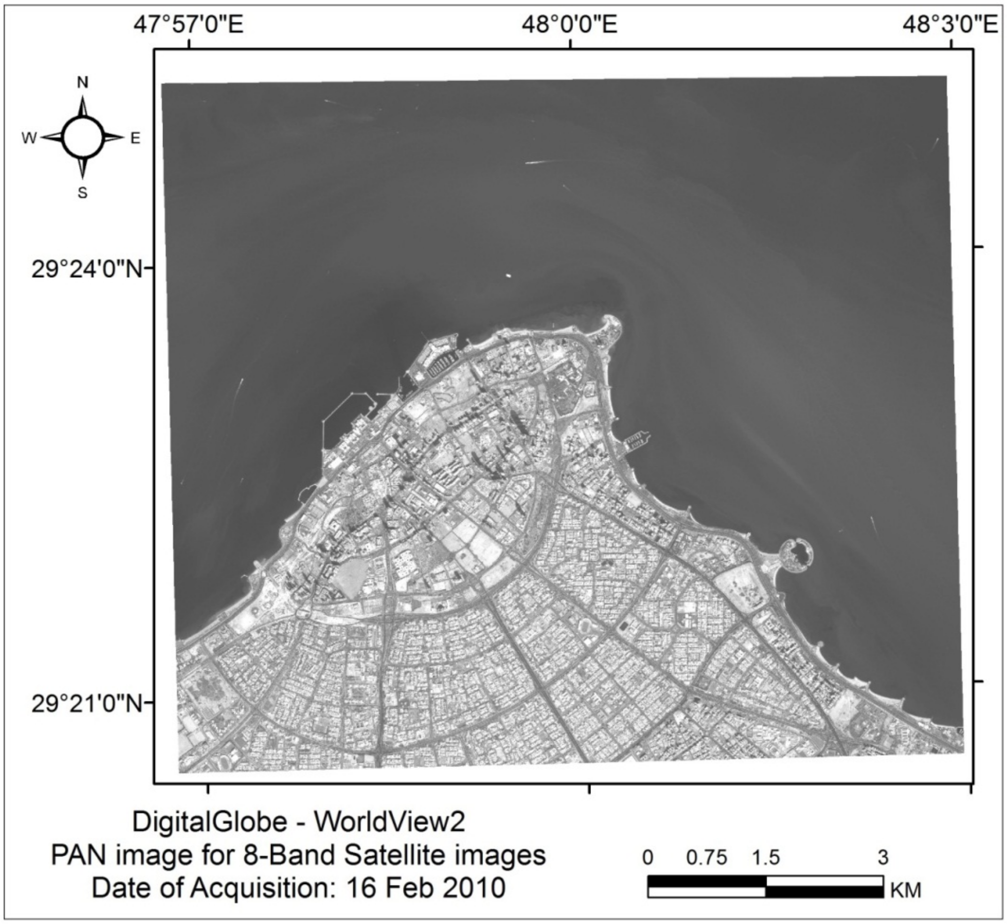

Figure 1 Area of Study (Pan Band)

Proposed methodology for haze modeling

The approach to select the suitable scattering model based on image data only will use the following conventions:

- (i) is the haze model, where (i) = {1, 2, 3, 4, 5}, as described in Table 1
- (x) is the exponent value of haze model (i), (x_i) = {-4, -2, -1, -0.7, -0.5}, as described in Table 1
- (j) is the band, where (j) = {1, 2, 3, 4, 5, 6, 7, 8}
- (λ) is the mean wavelength of the band, λ_j values are shown in Table 2

The proposed methodology is to compute the DOS value for each band separately and compute the values for the five models of relative scattering for the 8 bands. Then, compute the square difference between the percentage of DOS value and each model and select the model with a least square difference as shown in Figure (2).

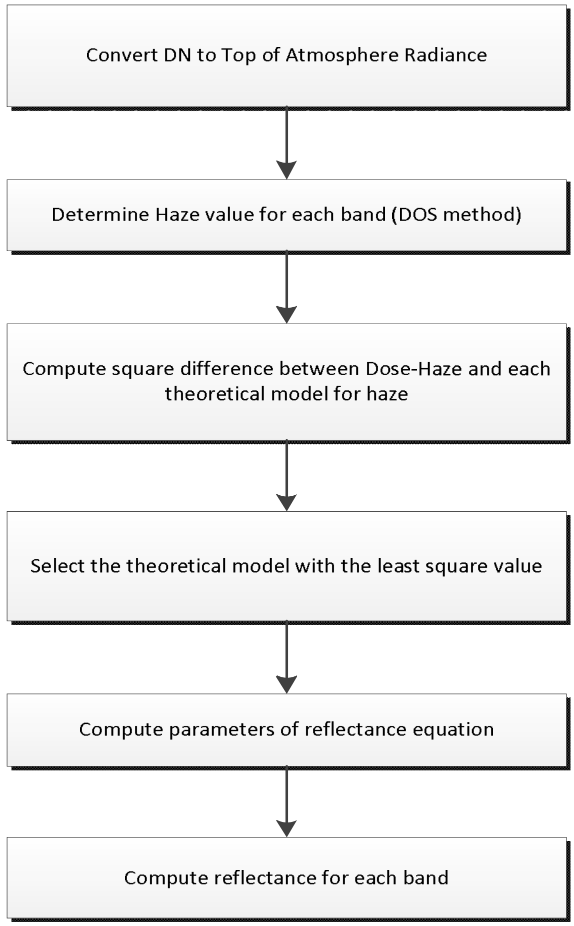

Figure 2 Flow chart for computing reflectance of 8-band images

The relation between haze model (M) and wavelength (λ) is defined by the relation:

$$M_{ij} \propto \lambda^{x}$$

The haze M_{ij} for Model (i) and band (j) is in direct relation with the exponent (x) of the wavelength (λ), where (x) is the related to atmospheric conditions. In order to maintain the same units, the percentage of total haze will be used.

Let the model M_i be the one of the five relative scattering models, where $i = 1$ *to* 5,

D is the DOS values computed for each band j, where $j = 1$ *to* 8 (8 bands),

$$K_i = \sum_{j=1}^{8}(\%M_{ij} - \%D_j)^2$$

Where $\%D_j$ is the haze percentage of band (j) from total DOS haze (D),

And $\%M_{ij}$ is the haze percentage of band (j) from total haze (M_i), for atmospheric condition (i), and K is the square of the difference between $\%M_{ij}$ and $\%D_j$. The selected model M_i will have the condition: K_i is minimum.

Determine the DOS haze value for each band

For each band, there is a sharp increase in the number of pixels for non-zero DN values. This DN value is assumed to be the amount of haze in each particular band (Chavez 1988). By computing the histogram for each band, and observing the change in number of pixels for low values, the haze level in each band was computed, and then converted to its equivalent radiance values as displayed in Table (3).

Table 3 DOS values of haze in radiance

Band Name	DOS Radiance [$W\text{-}m^{-2}\text{-}sr^{-1}\text{-}\mu m^{-1}$]
Coastal	68.98
Blue	67.52
Green	50.77
Yellow	33.69
Red	24.42
Red Edge	14.67
NIR1	8.79
NIR2	4.99

Selection of haze model based on least square

Computing the square difference (K) between the DOS value (D) and the theoretical values (M), and the values of (K) are displayed in Table (4).

Table 4 Square of difference between haze model and DOS haze

Square of difference with DOS Radiance (K)					
Band Name	**very clear**	**Clear**	**Moderate**	**Haze**	**Very haze**
sum	203.6	75.2	256.9	345.3	412.7

The least square value is (K = 75.2), which refer to clear condition (x = -2), which will be applied for atmospheric correction.

Conclusion

The worldview-2 sensor delivers a higher spectral accuracy than traditional 4-bands. The DN values of the 8-band images have to be converted to earth surface reflectance in order to full investment of the sensed data. The image based atmospheric corrections are more practical than RTC however they are of less accuracy. The COST method of the DOS technique of image based atmospheric correction includes a reasonable approximation for atmospheric transmittance. But still the DOS technique does not maintain a unified scattering model for haze through all bands. The least square methodology used in this research is straight forward and leads to acceptable haze correction to 8-band images.

Acknowledgment

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