Abstract: Earth Observing 1 (EO-1) is the world's first satellite that carries a hyperspectral sensor—Hyperion, which has 242 spectral bands and a 30-m spatial resolution. The objective of this research is to use the Hyperion image for deriving the forest biophysical variables, crown cover projection (CCP) and crown diameter (CD), in the study site of Longmenhe forest nature reserve, which located in the Three Gorges region of China. The processing methods of Hyperion data, including de-striping, noise reduction, radiometric and atmospheric correction by MODTRAN 4, are required prior to deriving. Using the processed pixel based surface reflectance data, the most effective and typical bands are evaluated for spectral mixture analysis. Then, an inverted geometric-optical model is successfully applied to derive and map CCP and CD by Hyperion. The sample plots with measured all kinds of forest attributes from fieldwork and a high resolution QuickBird image provide the necessary model input parameters and they are also the important data for accuracy estimation.

1. Introduction

Ecologically sustainable development and optimal management of natural resources is an essential ingredient of socio-economic development of any region and any country (Murai 1991). Among the various natural resources that are present on the terrestrial Earth surface, forests are one of the most important contributors that influence ecosystems with respect to Carbon storage and release. Quantitatively monitoring forests using remote sensing methods strongly supports the conservation and management strategies that take into account biodiversity, structures and the impact of the global carbon cycle.

Traditionally, quantitative retrieval methods for estimating forest biophysical variables are grouped into two major categories: statistical and physical approaches. Statistical methods are based mainly on vegetation indices or correlating features to quantities. Physical methods usually rely on inverting or assimilating canopy reflectance models (Liang 2004). A significant observed trend is that more and more empirical statistical models are being gradually replaced by physically based models, which have been developed mostly since the early 1980s. For example, Woodcock et al. (1994) estimated the mean tree size and cover for each forest stand from an inverting forest canopy reflectance model in Stanislaus National Forest; Scarth and Phinn (2000) determined the forest structural attributes using an inverted geometric-optical model in mixed eucalypt forests in Australia; Gemmell et al. (2002) measured boreal forest variables from Landsat TM data by inverting a hybrid geometric-radiative transfer model in Finland. Although these algorithms are prosperously used for monitoring the forest biophysical variables, the application of these models usually depend on different regional study sites and specific types of forest ecosystem. In addition, the authors also suggested that the development of new-generation imaging platforms would provide an opportunity to use high spatial and hyperspectral resolution remote sensing data for improving and calibrating physical based models.

Hyperion, one of the three sensors on the NASA EO-1 platform, launched on November 24, 2000, now orbits 1 min behind Landsat (Ungar, et al. 2003). As a pushbroom imaging instrument, Hyperion provides high resolution hyperspectral images capable of resolving 242 spectral bands (from 0.4–2.5 μm) with a 10-nm spectral resolution and a 30-m spatial resolution. The objective of this study is to using the Hyperion data for deriving and mapping two forest biophysical variables, crown cover projection (CCP) and crown diameter (CD), by a combined geometrical-optical and spectral mixture analysis model in the study area of Longmenhe forest nature reserve.

The Longmenhe reserve lies in the Xingshan county of Hubei province of China. The total reserve size is about 4644 ha and altitude varies around 1300 m above sea level. This study site includes 650 ha natural evergreen broadleaf forest and mixed deciduous broadleaf forest; 223 ha rare plant communities and 121 ha planted subtropical evergreen broadleaf forest. It is one of the most important research areas in China, mostly because of its location in the Three Gorges region and has just 80-km away from the Three Gorges Dam. For this study, a Hyperion image of June 10, 2004 was obtained and twice fieldworks in June of 2003 and 2005 were also carried out for collecting the necessary ground truth data. In total 40 sample sites (100mx100m) located in the study area were measured with all kinds of forest biophysical variables in each site. Another high resolution QuickBird image of 2003 provided the best reference for samples and field data locating.

2. Methods

The flowchart of general methods is shown in Fig.1. The Hyperion data processing, spectral mixture analysis and the geometric optical model are the keys of this study.
The currently used Hyperion Level 1B1 data have 242 bands of which 198 are nonzero and that are scaled by 40 for the VNIR and 80 for the SWIR to units of radiance. Several strips (data columns of poor quality) in this Hyperion data contain no information and lower radiance. Those abnormal pixels will be detected and replaced by the average radiance value of their immediate left and right neighboring pixels. The Minimum Noise Fraction (MNF) process can reduce the noises of image. Based on the Eigenvalue profile, the effective bands contain the most information will be selected to obtain the final inverted data. Atmospheric correction is for conversion of radiance to reflectance. In this study, retrieving at-surface reflectance of Hyperion data uses MODTRAN 4.

The Li-Strahler geometric optical model (Li and Strahler, 1992) was derived from the assumption that the Bidirectional Reflectance Distribution Function (BRDF) is a purely geometric phenomenon resulting from a scene of discrete three-dimensional objects being illuminated and viewed from different locations. The model also assumes that the resolution of remote sensing image is much larger than the size of individual crowns but smaller than the size of forest stands, and that the individual trees are randomly (Poisson) distributed within the pixel (Woodcock et al. 1994). The reflectance from each of the four scene components (sunlit/ shaded canopy and background) in this model is a function of the size and density of the canopies present. Among them, one component Kg (sunlit background) can be used to invert the model for deriving CCP and CD from a parameter of M. Kg is expressed easily using the Boolean model in (1). Where the term O (θ, φ) is the overlap function between viewing and illumination shadows as projected onto the background and the function in principal plane is shown in (2). Therefore, M can be solved in (3). Then, two formulas shown in (4)(5) indicate the relation of M to CCP and square of crown radii.

$$K_g = e^{-\pi M [\sec \theta' + \sec \phi']\left(\pi - t + \cos t \sin t\right)}$$  (1)

$$O(\theta, \phi) = \frac{1}{\pi} \left(\sec \theta' + \sec \phi'\right) \left(t - \sin \cos t\right)$$  (2)

$$M = -\frac{\ln(K_g)}{\left(\sec \theta' + \sec \phi'\right)\left(\pi - t + \cos t \sin t\right)}$$  (3)

Including:

$$\theta' = \frac{\pi}{2} - \arctan \left(\frac{\tan(\theta - \phi)}{r/b}\right)$$

$$\phi' = \phi$$

$$\theta'' = \theta$$

$$\phi'' = \phi$$

and

$$\theta'' = \arccos(\cos(\theta')\cos(\phi') + \sin(\theta')\sin(\theta')\cos(\phi - \phi'))$$

$$CCP = 1 - e^{-\pi M}$$  (4)

$$R^2 = \frac{\sqrt{(1 + \omega)^2 - 4 + 4 \cdot V(m)}}{2\omega} - (1 + \omega) \cdot M$$  (5)

Parameters: h, tree height from ground to mid-crown; b, crown radii in vertical direction; r, crown radii in horizontal direction; V (m), variance of M to the mean of study area; w, variability of r'.

If r/b, h/b, the solar zenith and azimuth (θi, φi), the view zenith and azimuth (θv, φv), the local slope and aspect (θs, φs), coefficient of w and Kg are known, CCP and CD will be derived successfully.

Spectral mixture analysis has been widely used to compute the percentages of several cover types, especially by hyperspectral data. A linear spectral unmixing model is shown in (6). S is the reflectance of a pixel, K are the endmember (pure reflectance spectra) fractions for sunlit/shaded canopy and background (G, C, T, Z). In this model, there are only four ground scene elements in one pixel and the sum of fractions is 1, see (7). In this study, the suitable endmembers are selected through analyzing the spectra of Hyperion data in terms of ground truth data and a high resolution QuickBird image.

$$S = k_g \cdot G + k_c \cdot C + k_t \cdot T + k_z \cdot Z$$  (6)

$$k_g + k_c + k_t + k_z = 1$$  (7)
3. Results

The processed Hyperion image with at-surface reflectance is geometric corrected by a Landsat TM data (Xu, 2004) and finally total 158 effective bands are used into the linear spectral unmixing model. The inputs of inverted geometric optical model are listed in Fig 2. Other important parameters for this model are derived from 10 sample sites of field data and the mean values are 0.4 (r/b), 2.18 (h/b) and 1.28 (w).

After running the model, Fig. 3 display the final mapping results of CCP and CD distributed in Longmenhe study area. Using the ground measured CCP and CD data from 30 sample sites to validate the model derived values (mean value of 3x3 pixels matches one sample site data). The correlation curves are shown in Fig. 4. , R of CCP is 0.65944 and R of CD reaches 0.71582.

4. Summary

The validity result is shown that most of the interpreted values of CCP are less than the measured data and the values of CD are little bit larger than field data. So the accuracy of model-derived results mainly depends on the detecting of Kg value from Hyperion image and the endmember selection is a key process. In addition, the processing for Hyperion data and the model input parameters determination needs more careful analysis in the future studies.

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References


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