Study on the Relationship between the Forest Canopy Closure and Hyperspectral Signatures

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Abstract: Forest canopy density is an ideal representative of the forest habitat situations. It can directly or indirectly depict the canopy structure and gap size in the forestland, thus could be applied to assessment of wildlife's diversity. Since population survey of vegetation and wildlife diversities is a key issue for sustainable forest ecosystem management, many research efforts have been focused on forest canopy density using multispectral data in the last two decades. Unfortunately, prediction of canopy density using large scaling remote sensing data remains a challenging issue. Due to recent advances in hyperspectral image sensors hyperspectral imagery is now available for environmental monitoring. In this paper, we conduct experiments to monitor complicated environments of forestland that can be captured by using hyperspectral imagery and further be analyzed to test a prediction model of forest canopy density. The results show that 95% of canopy density could be well described by using 2 difference vegetation indices (DVIs), which are difference of blue and green reflectances ρ_{band_100}-ρ_{band_150} and difference of 2 short wave infrared reflectancse ρ_{band_406}-ρ_{band_410} With the wavelengths of band no. 100, 150, 406, and 410 specified by 462.39 nm, 534.40 nm, 918.22 nm and 924.41 nm respectively.
Keywords: Forest Resources Inventory, Crown Closure, Canopy Density, Remote Sensing, Hyperspectral Data.

1. Introduction

The Rio declaration in the AGENDA 21 [7] indicated that environmental protection and natural resources conservation should be the primary guidance for each country of the planet. This means that resources should be protected and managed under a safe and reusable direction which was said to be sustainable management, especially for natural resources. Forest is the major cover of the land. If the forest ecosystem succession moves toward the positive direction, resources conservation and environmental protection will be achieved. The US Department of Agriculture (USDA) pointed it out that the extents of the area by forest types relative to total the forest area and fragmentation of forest types were important indicators for ecosystem diversity. It is, therefore, why much research has been directed to aim at identification of forest properties with help of remote sensing techniques in the past decades. This paper conducts a field experiment by measuring the spectral reflectance of vegetation with varying closure densities. It aims is to explore the relationship between the closure density and the spectral signatures.

2. Materials and Methods

1) Infrastructure of Field Measurement of Plant Reflectance

A GER (Geophysical & Environmental Research) 2600 spectroradiometer was adopted in this field measurement. The instrument was designed to cover the electromagnetic energy from 350 nm to 2500 nm and split them into 605 bands. The data were proven to be useful in revealing the spectral characteristics of plants [2]. In the field experiment, we first set up a forest stand in a nursery equipped with an automatic experimental frame. The instrument with a FOV of 10 degree (b)

looked down vertically at 3.6-meter height above the ground (H) and was controlled with a set of semi-automatic facilities. The average height of the plants is about 1.2 meters. According to the formula Eq. (1) in [1],

$$D = Hb \tag{1}$$

the instrument covered an area of 38.4 by 38.4 cm^2 per pixel. Fig. 1 shows the coverage of each pixel of this experiment. To order to measure the spectral data, we first measure the solar radiance (R_S) on the spectra based on reflectance standard, and then the radiance reflected from objects (R_O). Dividing R_O by R_S yields the object's reflectance given by Eq. (2) [2].

$$\boldsymbol{t} = R_O / R_S \tag{2}$$

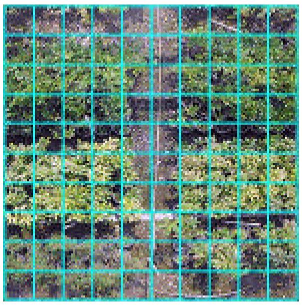

Figure 1. Pixels of the experimental field

Fig. 2 shows the reflectance curves of various targets used in the experiment whose crown densities were are different.

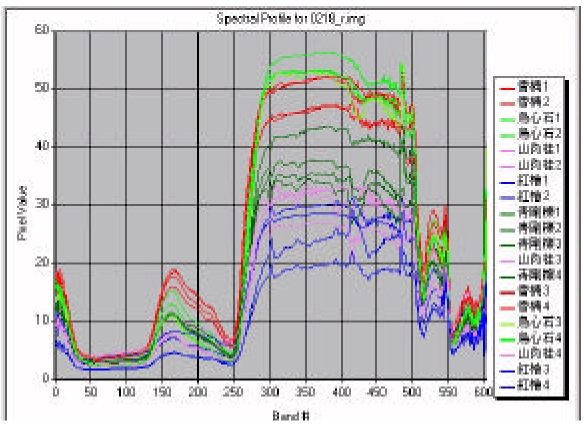

Figure 2. Reflectance curves of some pixels of the vegetative species

2) Crown Density Extraction

A maximum likelihood classifier (MLC) was applied to explore the extent of the vegetation in a pixel area from the digitized color image of an aerial photo in Fig. 1. Figure 3 shows the binary image of the crown closure in the experimental field. Green portion is the areas covered with the green leaves while the white portion is not. The grids in Figs. 1 and 3 represent one-to-one correspondence of the same area of each pixel in the field position.

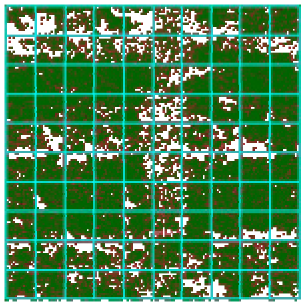

Figure 3. Crown closure map of the experimental field

3) Regression Analysis of Vegetation Spectral

The relationship between the hyperspectral reflectance of wavelength variables (X) and the vegetative canopy closure (y) resident in pixels in Eq. (3) was examined by the multiple regression analysis. All of the original 605 bands of the GER2600 spectroradiometer with derived spectral indices, such as difference vegetation index, DVI in Eq. (4) and normalized difference vegetation index, NDVI in Eq. (5) were also applied and used as independent variables for regression analysis.

$$y = \hat{a}\mathrm{X} \tag{3}$$

$$\mathrm{DVI} = r_{band\_i} - r_{band\_j} \tag{4}$$

$$\mathrm{NDVI} = \frac{r_{band\_NIR} - r_{band\_\mathrm{Red}}}{r_{band\_NIR} + r_{band\_\mathrm{Red}}} \tag{5}$$

3. Results and Discussions

Results of the multiple regression analysis reveal that the maximum R^2 could be achieved using 23 spectral bands, i.e. band no. 173 (green) and 226 (red), and 306, 427, 488, 508, 510, 544, 549, 557, 562, 563, 564, 566, 580, 582, 585, 586, 589, 590, 591, 597, 600 (near infrared). Detail descriptions for spectral information of these bands can be found in [6]. Comparing the results against those in [3], this model is not so good in predicting the canopy closure with the hyperspectral signatures. This is because a multicollinearty effect may exist in the model and may reduce the accuracy predicted by the model. This situation could be improved by introducing the vegetation index. The test results of four concise models using DVI and/or NDVI indices are tabulated in Table 1 to show their comparative performance, with the labels "b" and "std_Error" represent the regression coefficient of predictor(s) and its/their standard error; ***t*** and sig represents the student's ***t*** statistic of ***b*** and significance level respectively. The VIF means the variance inflation factor [5], and R^2 depicts the coefficient of determination of regression model; R^2 ranges from 0 to 1, and a higher R^2 means the model independent variables predict the dependent variable better. Although both model 3 and 4 produced the highest R^2, but model 4 was preferred due to the fact that it used only two DVI indices, B406-B410 (NIR difference) and B100-B150 (Blue and Green difference) because of its lower VIF value. Model 3 is similar to model 4 except that the predictor NDVI2 had a non-significant coefficient (Sig. > 0.05). The VIF of the regression coefficients of the predictors, NDVI2 and B406-B410 were too large to make the estimated canopy closure more stable and reliable for model 3. Model 1 with the predictor NDVI2 is also recommended for canopy closure estimation because of its coefficient of determination was almost identical to that of model 4, but no multicollinearty reduced this model' s efficiency.

Table 1. Test results of four regression models for canopy closure.

Model	Predictors 1)	***b***	Std_Error	***t***	Sig.	VIF	R^2
1	NDVI2	83.250	1.891	44.015	.000	1.000	.948
2	NDVI2	58.582	10.767	5.441	.000	33.741	.950
	B406-B410	18.199	7.825	2.326	.022	33.741	
3	NDVI2	2.022	18.927	.107	.915	115.685	.956
	B406-B410	84.067	19.983	4.207	.000	244.170	
	B100-B150	-65.275	18.384	-3.551	.001	34.666	
4	B406-B410	86.157	4.047	21.287	.000	10.111	.956
	B100-B150	-66.928	9.882	-6.773	.000	10.111	

1) NDVI2 = (B501-B250)/(B501+B250); B100, B105, B250, B406, B410, and B501 represents the band no. 100, 105, 205, 406, 410, and 510 respectively.

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