Investigation of Linear Spectral Mixtures of the Reflectance Spectra using Laboratory Simulated Forest Scenes

Baoxin Hu[1,2], John R. Miller[1], Jinnian Wang[1,4], and Narendra S. Goel[3]

1. Dept. of Physics and Astronomy, York University, 4700 Keele St. Toronto, ON M3J 1P3, Canada
2. Canadian Space Agency, 6767 route l' Aeroport, St Hubert, QC J3Y 8Y9, Canada
3. Dept. of Computer Science, Wayne State University, Detroit, Michigan 48202, USA
4. Institute of Remote Sensing Applications, Chinese Academy of Sciences, P.O.Box 9718, Beijing, China

Emails: baoxin@yorku.ca/jrmiller@yorku.ca/ngoel@attglobal.net

Abstract-- **In this study, we used laboratory data to investigate the effects of multiple scattering between tree crowns and snow background on the linearity of mixtures of the reflectance of winter forest scenes. Several scenes were designed in the laboratory to simulate the natural forest winter landscape. Hyperspectral images of the designed scenes were acquired by the Compact Airborne Spectrographic Imager (CASI). Each scene was decomposed by linear spectral unmixing of the scene reflectance spectrum using sunlit crown, shaded crown, sunlit background, and shaded background as end members. The SPRINT canopy model was employed to evaluate the results of the linear spectra unmixing approach. Our results show that if a linear unmixing approach is used for the designed scenes, the errors in the fractions of end members are as high as 25 percent relative to the fractions obtained by the SPRINT model. This investigation suggests that non-linear mixture models may be needed to account for the multiple scattering between tree crowns and snow background.**

I. INTRODUCTION

Linear spectral mixture models have been widely used in the mathematical description of reflectance properties of forest scene [1,2,3]. However, attempts to retrieve biophysical parameters of forest canopies from the remote sensing data using model inversion is normally seriously compromised due to the spatial variation of understory vegetation[4]. Consequently, winter remote sensing data has attracted attention, due to the relatively uniform and spectrally featureless snow background [3,4]. However, due to the multiple scattering between tree crowns and snow background, nonlinear process may dominate the reflectance properties of a winter forested scene. If a linear mixture model is applied to a nonlinear system, the errors in the fractions of end members obtained from linear unmixing may be very large [5]. Effects of the nonlinear mixture between vegetation and soil on linear unmixing have been reported for the vegetated landscape [6,7]. These observations are based on the residual between the original reflectance being unmixed and the reflectance predicted by a linear mixture model. Borel and Gerstl [8] used a radiosity-based model to demonstrate that nonlinear mixture effects occur when multiple scattering effects are considered; and in the near-infrared range surface reflectance obtained by their model almost twice as high as with the linear mixture model.

In this study, we used laboratory data to systematically investigate the issues in the application of linear spectral unmixing in a forested scene. We analyzed effects of background reflectance, crown transparency, and stem density on the linearity of mixture of the scene reflectance.

II. DATA AND DATA PROCESSING

A few scenes were designed to simulate, in the laboratory, the natural forest winter landscape. Two kinds of objects, opaque and translucent, were mounted on stems to simulate forest crowns on trunks. These "trees" (both opaque and translucent) were randomly [9] placed on a mounting board covered with a white background. Opaque and translucent trees were separate and each occupied an area of 40 cm by 40 cm on the same mounting board. The four edges of each scene (with opaque or translucent trees) were clearly marked on the mounting board to identify the scenes from remote sensing imagery. Canopies of both opaque and translucent trees were designed, with two tree densities: sparse and dense.. For the sparse canopies 40 trees were planted in an area of 40 cm by 40 cm, while 100 trees were used for the dense canopies. The scene illumination was generated using a 1000 W tungsten lamp at the focal point of a 120-cm focal length Fresnel lens that provided the incident collimated radiation [9]. For these experiments an illumination angle of 40^o was used. Hyperspectral images of these simulated forest scenes were acquired by the Compact Airborne Spectrographic Imager (CASI), a pushbroom imager, by moving the entire scene at a constant rate, perpendicularly with respect to the CASI field-of-view. The hyperspectral CASI images were acquired in 72 spectral channels covering the spectral region 414 to 914 nm, at a nominal spectral resolution of 7.5 nm. With the target scene observed within 15.3/- 15.3 degrees from the CASI nadir, nadir viewing was assumed for all of the subsequent image analysis. CASI imagery was also collected over a white Spectralon panel

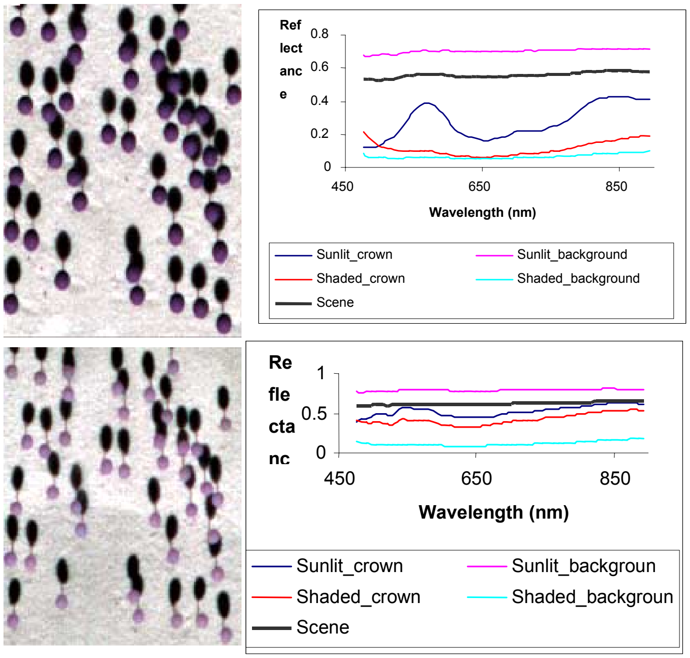

Fig.1 CASI colour composite images over the scenes with sparse opaque (left top) and translucent crowns (left bottom). The spectral bands used for the images are band 50 (770nm), band 30 (618nm), and band 20 (543nm). The spectra of the end members, sunlit crown, sunlit background, shaded crown, and shaded background, and the scenes are shown at the corresponding positions in the right panels. These spectra were derived from CASI images.

under the same imaging geometry. The radiance of the white Spectralon panel was used as a reference to calculate the reflectance of the scenes. The reflectance images of the scenes with sparse canopies are shown in the left panels of Fig1 as an example. The CASI images over the designed scenes (hereafter referred to simply as "scenes") were decomposed by linear spectral unmixing procedure described in [3]. The areal fractions of the end members in these scenes were calculated by the SPRINT canopy model [10] for comparison.

III. LINEAR SPECTRAL UNMIXING OF THE REFLECTANCE OF THE SINULATED FOREST SCENES WITH SPARSE CANOPIES

As demonstrated by the images in the left panels of Fig. 1, these scenes are mainly composed by sunlit crown, sunlit background, shaded crown, and shaded background. Therefore, sunlit crown, sunlit background, shaded crown, and shaded background are considered as the four end members of these scenes. Pixels of each end member class were visually identified and the average reflectance spectra of these pixels were used as the end member spectra for this class. The spectra of these four end members are shown in right panels of Fig.1. The reflectance of each scene in each spectral band was calculated as the average value of all pixels in the scene (called the observed scene reflectance), and its spectra are shown by the dark line in the right panels of Fig.1.

The linear spectral unmixing procedure in [3] was used to obtain the fractions of end members. The results are shown in Table I. The reference fractions obtained by the SPRINT model are shown in Table I as well. It is clear from these results that the fraction of shaded crown cannot be obtained from the linear unmixing approach for these scenes, although the specific reason(s) are not obvious. This may arise because the shaded crown is not spectrally distinct from other end members, as shown in Fig. 1. From Table I, we can observe that for the scene with opaque crowns, the absolute errors (differences between the fractions obtained by SPRINT model and those by the linear unmixing) in the fractions of sunlit crown, sunlit background, and shaded background are 4.24%, 0.31%, and 6.07%, respectively. The relative errors (relative to the fractions obtained by the SPRINT model) are 38.76%, 0.43%, and 39.85%, respectively. For the scene with a white background, the high reflectance of the background enhances the multiple scattering between tree crowns and the background large. The reflectance spectra of the scene, therefore, depart significantly from a linear mixture of the reflectance spectra of sunlit crown, sunlit background, shaded crown, and shaded background. We can also observe in Table I that for the scene with translucent crowns, the absolute errors are 7.8%, 8.3%, and 1.6% in the fractions of sunlit crown, sunlit background, and shaded background; and the relative errors are 75.0%, 11.9%, and 9.3%, respectively.

Comparison of these results with those for the opaque case reveals that the errors in the fractions of sunlit crown, sunlit background, and shaded background obtained by the linear spectral unmixing approach are generally larger with translucent crowns. The large errors in the fractions of the end members may be caused by the relative increase in multiple scattering between crowns and the background due to the crown transparency.

IV. LINEAR SPECTRAL UNMIXING OF THE REFLECTANCE OF THE SIMULATED FOREST SCENES WITH DENSE CANOPIES

The linear spectral unmixing approach and the SPRINT model calculation were also used for the scenes with dense canopies (with 100 trees on an area of 40cm by 40cm). The results are shown in Table II. For the scene with opaque crowns, the absolute errors in the fractions of sunlit crown, sunlit background, and shaded background are 11.5%, 1.63%, and 10.2%, respectively, and the relative errors 38.9%, 4.25%, and 32.1%, respectively. For the scene with translucent crowns, the absolute errors in the fractions of sunlit crown, sunlit background, and shaded background are 24.6%, 28.0%, and 2.23%, respectively; and the relative errors are 88.2%, 78.3%, and 7.27%, respectively. These results show that the errors in the fractions of sunlit crown, sunlit background, and shaded background are larger for the scene with translucent crowns than for the scene with opaque crowns. Recall that the same phenomenon was also observed for the scenes with sparse canopies. The crown transparency increases the multiple scattering between crowns and the background, which leads to a scene reflectance for which nonlinear mixture contribution to the reflectance of the end members increases. Comparison between Table I and Table II reveals that the errors in the fractions for the scenes with dense canopies are larger than those obtained for the scenes with sparse canopies. This is because with the increasing of the number of tree crowns, the multiple scattering between crowns and the background is increased, and therefore nonlinear process dominates the spectra signature of the scenes.

V. CONCLUSIONS

In this study, CASI data over laboratory-scale forest-simulation scenes were used to investigate the effects of background reflectance, crown transparency, and stem density on the linear spectral unmixing expected in a forest stand. The SPRINT model was used to evaluate the fractions of end members obtained by the linear unmixing. For the scenes with a white background, the multiple scattering between crowns and background are quite large. The reflectance spectra of these scenes tend to be a nonlinear mixture of the reflectance spectra of sunlit crown, shaded crown, sunlit background, and shaded background. If linear unmixing is used for these scenes, the errors in the fractions of the end members are very large. For example, even for the scene with sparse opaque crowns, the relative error in the fraction of sunlit crown is 44.2%. The errors in the fractions are larger for dense canopies than for sparse canopies, and the errors are larger for translucent crowns than for opaque crowns. This is because the stem density and crown transmittance increase multiple scattering between crowns and the background. As a result, for the scenes with a white background, a non-linear mixture model is needed. In a future study, we will develop a mixture model to account for the multiple scattering between tree crowns and the background.

ACKNOWLEDGEMENTS

This work is supported in part by GEOIDE (GEOmatics Informed Decisions) and Canadian Space Agency.

TABLE I: FRACTIONS OF THE FOUR END MEMBERS, SUNLIT CROWN, SUNLIT BACKGROUND, SHADED CROWN AND SHADED BACKGROUND OBTAINED BY LINEAR UNMIXING AND SPRINT MODEL FOR THE SCENES WITH SPARSE CANOPIES.

		Sunlit Crown	Sunlit background	Shaded crown	Shaded background
O	Unmixing	0.094	0.695	0.0	0.211
	SPRINT	0.1094	0.7231	0.0152	0.1523
T	Unmixing	0.065	0.701	0.0	0.234
	SPRINT	0.1041	0.7016	0.0205	0.1739

O: Opaque; T: Translucent

TABLE II: FRACTIONS OF THE FOUR END MEMBERS, SUNLIT CROWN, SUNLIT BACKGROUND, SHADED CROWN AND SHADED BACKGROUND OBTAINED BY LINEAR UNMIXING AND SPRINT MODEL FOR THE SCENES WITH DENSE CANOPIES.

		Sunlit Crown	Sunlit background	Shaded crown	Shaded background
O	Unmixing	0.067	0.720	0.0	0.213
	SPRINT	0.2947	0.3873	0.0408	0.2772
T	Unmixing	0.204	0.480	0.0	0.316
	SPRINT	0.2794	0.3578	0.0561	0.3067

REFERENCES

[1] Hall, F. G., Shimabukuro, Y. E., and Huemmrich, K. F. " Remote sensing of forest biophysical structure using mixture decomposition and geometric reflectance model", *Ecol. Appl. 5,* 993-1013, 1995.

[2] Li, X, and Strahler, A. H., "Geometrical-optical modeling of a conifer forest canopy", *IEEE Trans. Geosci. Remote Sensing*, 23, 705-721, 1986.

[3] Hu, B., Miller, J. R., Chen, J. M. and Hollinger, A. B., "Retrieval of the canopy leaf area index in the BOREAS flux tower sites using linear spectral mixture analysis", *Remote Sens. Environ.* In press.

[4] Hu, B., Inannen, K. and Miller, J. R., "Retrieval of Leaf Area Index and canopy closure from CASI data over the BOREAS flux tower sites"*, Remote Sens. of Environ.*, *74*, 255-274, 2000.

[5] Mustard, J. F. and Sunshine, J. M., "Spectral analysis for earth science investigation", in *Remote Sensing for theEarth Sciences* (edited by A. N. Rencz), John Wiley & Sons Inc., New York, 1999.

[6] Huete, A. R., Jackson, R. D., and Post, D. F., "Spectral response of a plant canopy with different soil backgrounds", *Remote Sens. Environ.* 17*:* 37-53, 1985.

[7] Smith, M. O., Ustin, S. L., Adams, J. B., and Gillespie, A. R., "Vegetation in deserts: I. A regional measure of abundance from multispectral images", *Remote Sens. Environ.* 31*:* 1-26, 1990.

[8] Borel, C. C., and Gerstl, S. A. W., "Nonlinear spectral mixing models for vegetative and soil surfaces", *Remote Sens. Environ.,* 47: 403-416, 1994.

[9] Soffer, R., "Bidirectional reflectance factors of an open tree canopy by laboratory simulation", Master Thesis, York University, Toronto, Canada, 1995.

[10] Goel, N. S. and Thompson, R. L., "A snapshot of canopy reflectance models and a universal model for the radiation regime", *Remote Sensing Reviews,* 18: 197-225, 2000.