Recognition of Semi-Arid Vegetation Types Based on MISR Multi-Angular Observations and Surface Anisotropy Patterns Inversed by Bidirectional Reflectance Models

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Abstract: Mapping accurately community type is one of main challenges for monitoring semi-arid grasslands with remote sensing. Multi-angle approach has been proved useful for mapping vegetation types in desert. Multi-angle Imaging Spectro-Radiometer (MISR) provides 4 spectral bands and 9 angular observations. In this paper, several classification experiments were done to find the optimal combination of MISR multi-angular observations to mine the information carried by MISR data as effective as possible. The experiments show the following findings: 1)The combination of MISR 4 spectral bands nadir observation and red and near infrared bands C, B, A camera observations can obtain the best vegetation type differentiation at community level in New Mexico desert. 2)The *k* parameter at red band of Martonchik-Rahman-Pinty-Verstraete (MRPV) model and the structural scattering index (SSI) can bring additional useful information to land cover classification. 3)The information carried by the two parameters, however, is less than that carried by surface anisotropy patterns described by the MRPV model and a linear semi-empirical kernel-driven bidirectional reflectance distribution function model, RossThick-LiSparse-Reciprocal model. These experiments prove that multi-angular data raises the classification accuracy from 45.4% of nadir observation to 60.9%, and with surface anisotropy patterns derived from MRPV and RossThick-LiSparse-Reciprocal accuracy 67.5% can be obtained when maximum likelihood algorithms are used. Support vector machine algorithms can raise the classification accuracy to 76.7%. This research suggests that multi-angular observations, surface anisotropy patterns and SVM algorithms can improve semi-arid vegetation type differentiation remarkably.

1. Introduction

New sensor and new classification methods in remote sensing are providing capabilities for mapping and monitoring the desert environment as never before. A community types may be defined as an aggregation of plant types which demonstrate mutual interrelationships between species and between species and environment. Community type differentiation is a classification problem in which the classes are the recognized plant community types and also is an approach to monitoring semi-arid grasslands. It implies a larger number of classes which differ more subtly than the border categories assigned to regional or global classification schemes. The Multi-angle Imaging SpectroRadiometer (MISR) (Scott Lewicki et al. 2003) on board the Terra platform provides new and unique opportunities to record the anisotropy of land surfaces by quasi-simultaneous 4 spectral bands (blue, green, red and near-infrared) nadir observation and 8 off nadir observations (26.1, 45.6, 60.0 and 70.5 degrees from the vertical both forward and afterward of nadir) measurements from space. In this paper, an innovative classification is proposed. This approach uses MISR data, surface anisotropy patterns derived from MRPV model (Rahman et al., 1993) and the linear semi-empirical kernel-driven bi-directional reflectance distribution function (BRDF) (Wanner et al., 1995).

This paper emphasizes a distinctive capability provided by surface anisotropy patterns for surface cover monitoring. Our approach is based on an analysis of using data acquired by MISR/Terra instruments, surface anisotropy patterns estimated by the inversion the MRPV model and AMBRALS RossThick-LiSparse-Reciprocal model at red and near infrared wavelength. All surfaces, including natural and man-made, show some degree of spectral anisotropy when illuminated by a point source of light in solar domain. The surface anisotropy depends on the three-dimensional character and optical properties of the surface. This means that the surface anisotropy can be used to character the surface target. It should be reasonable to introduce the surface anisotropy patterns as additional information dimensions into classification. It is well-known that MRPV model is used in MISR BRDF/albedo product (Diner et al. 1999) and AMBRALS is used in MODIS BRDF/albedo product (Strahler and Muller, 1999). In other words, they are two main operational BRDF models. So we use MRPV model and AMBRALS model to inverse the anisotropy pattern of surface reflectance from MISR observation.

This paper also investigates some indices derived from BRDF computation, such as parameter *k* of MRPV model (Pinty, 2002) and the structural scattering index (SSI) (Gao et al, 2003). They have be proposed to uncover the surface heterogeneity at the subpixel.

2. Study Area

Our study area lies within the Chihuahuan semi-desert province, which stretches across southeastern Arizona, southern New Mexico, and western Texas. The intensive study sites are the Jornada Experimental Range in southern New Mexico near Las Cruces (a USDA/ARS and LTER research site and a NASA EOS Land Validation Core Site (Morisette et al. 1999) and Sevilleta National Wildlife Refuge in central New Mexico near Albuquerque (an LTER, USFWS and NASA EOS Land Validation Core Site (Ritchie, et al. 2000). Jornada Experimental Range is about 78,266 hectares, is located between the Rio Grande floodplain on the west and the crest of the San Andres Mountains on the east. Its mean elevation is about 1350m. The Sevilleta National Wildlife Refuge is approximately 100,000 hectares in size, consisting of two mountain ranges and the Rio Grande valley in between. The Sevilleta National Wildlife Refuge lies at the junction of several major biomes of the American Southwest, elevational range (1,350 to 2,797m). In this research, we select MISR data from May 24 to June 3, 2002. This period is the end of dry season. All shrubs are leafed out but grasses and some other small plants are dormant.

3. Method

In order to mine the information carried by MISR data as effective as possible, this paper uses maximum likelihood classification and support vector machine (SVM) classification to perform several classification experiments. The overall accuracy and kappa index were calculated for every classification case. Maximum likelihood classification assumes that each spectral class can be described by a probability distribution in multi-spectral space. Such a distribution describes the chance of finding a pixel belonging to that class at any given location in multi-spectral space. SVM does not need a probability distribution of a spectral class. SVM is inspired from statistical learning theory. The foundations of SVM have been developed by Vapnik (1995) and are gaining popularity due to many attractive features.

4. Results and Discussion

The area covered by Jornada and Sevilleta vegetation maps is totally 23,978 pixels (250 meter spatial resolution), around 1492.4 square kilometer. We randomly pick up half (11,994 pixels) as training set and another half (11,984 pixels) as testing set for maximum likelihood classification and support vector machine classification algorithms. We select 19 classes for these classification experiments, where there are 6 classes from the Jornada and 13 classes from the Sevilleta.

The overall accuracy and kappa index of maximum likelihood classification accuracy and support vector machine are listed in from table 1 to table 5. The experiments in table 1 show that MISR nadir 4 spectral bands observations do not provide high accuracy. Though trying various combination of nadir and multi-angular observations, we found that the combination of 4 multi-spectral (blue, green, red and near infrared) nadir observations and multi-angular (Cf, Bf, Af, Aa, Ba, Ca cameras) red and near infrared observations can reach the highest accuracy. Therefore we use this combination as the fundamental multi-spectral multi-angular data set for the subsequent experiments. In table 2, we certify the suitability of *k* parameter at red band of MRPV model and SSI as additional information dimension in classification. The two parameters are not as good as the surface anisotropy described by the *ρ0*, *k*, *b* of MRPV model or the *iso*, *vol*, *geo* of AMBRALS model in table 3. The AMBRALS model enjoys a little bit higher accuracy than the MRPV model. The combination of nadir multi-spectral observations and the surface anisotropy described by the AMBRALS model even provide the higher accuracy than MISR original multi-spectral and multi-angular observations. The SVM classification results in table 4 and table 5 show that SVM can exploit the information carried on by MISR observations effectively. MISR original multi-spectral and multi-angular observations have almost the same classification accuracy as its combination with other additional information. The surface anisotropy patterns described by MRPV model and AMBRALS model should be compatible each other, because the better results always can be gotten when they are used together. The multi-spectral nadir observations with surface anisotropy described by AMBRALS model and MRPV model basically can provide the same accuracy as the multi-spectral and multi-angular observations. It suggests an innovative approach to improve classification and fusion data from multiple satellites. For example, we can use MISR, MODIS, AVHRR, VEGETATION to get surface anisotropy pattern though the AMBRALS and RPV model, then combine the pattern with nadir observation from MISR and ASTER for classification. The better result should be expected.

Table1. Max likelihood classifications at Original MISR data

Pure MISR Data set	overall accuracy	Kappa index
Nadir blue, green, red, NIR	45.39	40.65
9 camera red	41.93	36.26
Nadir 4 bands, and 8 off-nadir camera red	56.78	52.19
9 camera red and NIR	54.78	49.81
Nadir 4 bands, and D camera red/NIR	48.54	43.79
Nadir 4 bands, and C camera red/NIR	55.56	51.11
Nadir 4 bands, and B camera red/NIR	56.49	52.14
Nadir 4 bands, and A camera red/NIR	54.33	49.96
Nadir 4 bands, and C/B camera red/NIR	58.34	53.81
Nadir 4 bands, and C/B/A camera red/NIR	60.91	56.52
Nadir 4 bands, and D/C/B camera red/NIR	55.52	50.72
Nadir 4 bands, and 8 off-nadir camera red/NIR	59.38	54.78

Table 2 Max likelihood classifications at combinations of MISR data and *k* parameter at red of MRPV and SSI

Data set		overall accuracy	Kappa index
MISR nadir	*k*_red	51.62	47.07
	SSI	46.65	41.93
	*k*_red and SSI	51.56	47.02
MISR multi-angle	*k*_red	61.96	57.61
	SSI	61.10	56.71
	*k*_red and SSI	61.77	57.42

Table 3 Max likelihood classifications at combinations of MISR data and surface anisotropy patterns

Data set		overall accuracy	Kappa index
MISR nadir	*ρ0kb*	56.61	52.33
	Isovolgeo	61.97	58.00
	ρ0kb_isovolgeo	64.85	60.96
MISR multi-angle	*ρ0kb*	64.45	60.31
	Isovolgeo	65.54	61.51
	ρ0kb_isovolgeo	67.49	63.60

Table 4 Support Vector Machine classifications at combinations of MISR data and *k* parameter at red of MRPV and SSI

Data set		overall accuracy	Kappa index
MISR nadir	*k*_red	67.12	62.41
	SSI	66.15	61.22
	original data	64.31	59.09
MISR multi-angle	*K*_red	75.62	72.24
	SSI	75.83	72.50
	original data	75.56	72.21

Table 5 Support Vector Machine classifications at combinations of MISR data and surface anisotropy patterns

Data set		overall accuracy	Kappa index
MISR nadir	*ρ0kb*	72.10	68.16
	Isovolgeo	74.62	71.06
	ρ0kb_isovolgeo	75.62	72.22
MISR multi-angle	*ρ0kb*	75.67	72.31
	Isovolgeo	76.60	73.38
	ρ0kb_isovolgeo	76.73	73.50

5. Conclusion

The conclusion in our research can be summaried as follows.

(1) In the classification experiment, the essentially additional information are provided by the *ρ0*, *k*, *b* parameter of MRPV model and *iso*, *vol* and *geo* of AMBRALS model at red and NIR bands. In other words, the whole shape of BRDF provides more information than any one of the parameters which describe the shape in these two models.

(2) The highest accuracy of classification is expected to obtain by using the following data together: 1) MISR nadir blue and green red and NIR observations; 2) multi-angular (C, B, A camera) red and NIR observations; 3) the *ρ0*, *k*, *b* parameter of RPV model and *iso*, *vol*, *geo* of AMBRALS model at red and NIR bands.

(3) Multi-angular observations provide more information than nadir observations. NIR observations are essentially helpful for the semi-desert vegetation type differentiation even NIR data are obtained at 1100 meter spatial resolution.

(4) The *k* parameter of RPV model and SSI of AMBRALS model do provide additional information to the classification. But the improvement is marginal.

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References

[1] Scott Lewicki, Catherine Moroney, Kathleen Crean, Scott Gluck, Kyle Miller, Mike Smyth, and Susan Paradise (2003). Earth Observing System, Multi-angle Imaging Spectro-Radiometer, Data Products Specifications, — Incorporating the Science Data Processing Interface Control Document. JPL D-13963, Revision K. December 12, 2003, Jet Propulsion Laboratory, California Institute of Technology. (http://eosweb.larc.nasa.gov/PRODOCS/misr/DPS/DPS_v31_RevK.pdf)

[2] H. Rahman, B. Pinty, and M. M. Verstraete (1993). Coupled surface-atmosphere reflectance (CSAR) model. 2. Semiempirical surface model usable with NOAA advanced very high resolution radiometer data. J. Geophys. Res., Vol. 98, pp.20,791-20,801.

[3] Wanner, W., Li, X., and Strahler, A. H. (1995). On the derivation of kernels for kernel-driven models of bidirectional reflectance. J. Geophys. Res. 100:21,077-21,090.

[4] David J. Diner, John V. Martonchik, Christoph Borel, Siegfried A. W. Gerstl, Howard R. Gordon, Yuri Knyazikhin, Ranga Myneni, Bernard Pinty, and Michel M. Verstraete (1999). Multi-angle Imaging Spectro-

Radiometer Level 2 Surface Retrieval Algorithm Theoretical Basis. December 2, 1999, Jet Propulsion Laboratory, California Institute of Technology (http://eospso.gsfc.nasa.gov/eos_homepage/for_scientists/atbd/docs/MISR/atbd-misr-10.pdf)

[5] A. H. Strahler, J.-P. Muller (1999), MODIS BRDF/Albedo Product: Algorithm Theoretical Basis Document, Version 5.0, April 1999. (http://modis.gsfc.nasa.gov/data/atbd/atbd_mod09.pdf)

[6] Bernard Pinty, Jean-Luc Wildlowski, Nadine Gobron, Michel M. Verstraete, David J. Diner (2002), Uniqueness of Multiangular Mesurements --- Part I : An Indicator of subpixel Surface Heterogeneity From MISR. IEE transactions on Geoscience and Remote Sensing, Vol.40, No.7, pp1560-1573

[7] Gao, F., C. B. Schaaf, A. H. Strahler, Y. Jin, and X. Li (2003). Detecting vegetation structure using a kernel-based BRDF model. Remote Sens. Environ., 86(2), 198-205.

[8] Ritchie, J.C., T.J. Schmugge, A. Rango, and F.R. Schiebe (2000). Remote Sensing Applications for Monitoring Semiarid Grasslands at the Sevilleta LTER, New Mexico. Pages 1969-1971 in: na,editor(s). Proceedings of the IEEE 2000 International Geoscience and Remote Sensing Symposium, 24-28 July 2000, Honolulu, Hawaii, Volume: V. Spring: IEEE GRSS

[9] Vapnik, V. (1995), The Nature of Statistical Learning Theroy. New York, NY: Springer-Verlag.

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