A Generic Procedure For BRDF Normalization of Remotely Sensed Data

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Abstract– A generic procedure for Bidirectional Reflectance Distribution Function (BRDF) normalization for airborne multispectral images has been developed and implemented as an add-on module of ENVI at the U.S. Department of Energy’s Remote Sensing Laboratory. The main advantage of this procedure is that it does not require multiple image acquisitions over the same area for establishing empirical BRDF functions.

I. INTRODUCTION

Bidirectional Reflectance Distribution Function (BRDF) normalization has been a long-time challenge in spectral remote sensing. Publications of the last decade have concentrated on debating which mathematical model best represents the BRDF effects in remote sensing data. Adaptations of the theoretical BRDF models in industrial practice have been few, because most surveying and mapping companies do not have the luxury to acquire multi-angular observations needed for establishing empirical BRDFs over a project area.

During recent research, we developed a Principal Spectral Angle Projection clustering algorithm and, subsequently, a generic procedure for BRDF correction and normalization of airborne multispectral scanner data. This paper outlines the algorithm and procedure adopted and the related software prototype system.

II. KERNEL-BASED BRDF MODELS

The kernel-based approach toward the BRDF normalization of remotely sensed data has gained momentum in recent years [1, 2], especially due to the prominent work of the NASA MODIS team [3]. The basic assumption of the kernel model is that the BRDF function can be empirically expressed as a linear combination of three basic BRDF kernel functions, namely, isometric, geometric and volumetric. Mathematically, the BRDF function can be expressed by:

$$R(\theta_i, \theta_r, \phi) = f_{iso} + f_{vol} K_{vol}(\theta_i, \theta_r, \phi) + f_{geo} K_{geo}(\theta_i, \theta_r, \phi) \quad (1)$$

The constants f_{iso} , f_{vol} and f_{geo} depend on the wavelength of the data and the material class on the ground. A number of volumetric and geometric kernels have been developed and demonstrated by the MODIS team [4]. An algorithm using these special kernel functions called AMBRALS (Algorithm for MODIS Bidirectional Reflectance Anisotropy of the Land Surface) was used for the MODIS BRDF/Albedo product.

The AMBRALS model has been adopted for prototyping the BRDF normalization procedure discussed in this paper. The main difference between our approach and that of the MODIS team is in the acquisition of multi-angle observations. MODIS’ approach is pixel-based and relies on multi-date (16 days) observations to obtain multi-angle sampling of the same pixel. Our approach is cluster-based and relies on a rough, BRDF-less-dependent, clustering algorithm for generating initial clusters. Our approach does not require multiple imagery acquisitions of the project area. Obviously, the success of our approach depends strongly on the success of the initial BRDF-less-dependent clustering process.

III. PRINCIPAL SPECTRAL ANGLE PROJECTION CLUSTERING

A clustering algorithm usually begins with the definition of the closeness of two samples (pixels). We began looking for a closeness measure that would be less dependent on the BRDF effect. The first potential measure investigated was the cosine of the spectral angle between two spectral vectors. Let us look at the very primitive Minnaert BRDF [5]:

$$\mathbf{r} = \mathbf{r}_{observed}(\mathbf{q}_i, \mathbf{q}_r, \mathbf{j}) = \frac{\mathbf{r}_0 (\cos \mathbf{q}_i \cos \mathbf{q}_r)^{k-1}}{p}, \quad (2)$$

where $\mathbf{r}_0$ is the correspondent Lambertian reflectivity and k is a constant (limb darkening parameter). If we assume that k is independent of the wavelength in the appropriate range, say in the visible range, then for the given spectral vector $\bar{\mathbf{r}} = (\mathbf{r}_1, \dots, \mathbf{r}_B)$, where B is the number of spectral bands in the data set, we have:

$$\begin{aligned} \bar{\mathbf{r}} &= \frac{(\cos \mathbf{q}_i \cos \mathbf{q}_r)^{k-1}}{p} (\mathbf{r}_{0,1}, \dots, \mathbf{r}_{0,B}) \\ &= \frac{(\cos \mathbf{q}_i \cos \mathbf{q}_r)^{k-1}}{p} \bar{\mathbf{r}}_0 \triangleq F(\mathbf{q}_i, \mathbf{q}_r) \bar{\mathbf{r}}_0 \end{aligned} \quad (3)$$

where $F(\mathbf{q}_i, \mathbf{q}_r)$ is a factor independent of the wavelength. Suppose that there are two spectral vectors $\bar{\mathbf{r}}_1$ and $\bar{\mathbf{r}}_2$ in the data set. One can easily verify that the cosine of the angle between them is:

$$\cos(\bar{\mathbf{r}}_1, \bar{\mathbf{r}}_2) = \frac{\bar{\mathbf{r}}_1 \bullet \bar{\mathbf{r}}_2}{\|\bar{\mathbf{r}}_1\| \|\bar{\mathbf{r}}_2\|} = \frac{\bar{\mathbf{r}}_{0,1} \bullet \bar{\mathbf{r}}_{0,2}}{\|\bar{\mathbf{r}}_{0,1}\| \|\bar{\mathbf{r}}_{0,2}\|} = \cos(\bar{\mathbf{r}}_{0,1}, \bar{\mathbf{r}}_{0,2}). \quad (4)$$

This suggests that the cosine of the spectral angle is somehow independent (under the Minnaert BRDF approximation) of the incidence-view geometry. Additionally, if both spectral

vectors $\bar{\mathbf{r}}_1$ and $\bar{\mathbf{r}}_2$ are from the same material class, then we should have $\cos(\bar{\mathbf{r}}_1, \bar{\mathbf{r}}_2) \approx 1$.

In more recent research by [6], for practical application purposes, an extended Minnaert model was proposed for BRDF correction of satellite images. This extension still has the basic form of the Minnaert formula:

$$\mathbf{r}_{observed}(\mathbf{q}_i, \mathbf{q}_r, \mathbf{j}) = \mathbf{r}_0 f(\cos \mathbf{q}_i, l) f(\cos \mathbf{q}_r, s) \quad (5)$$

Ignoring the details of the f function, we can still write $\mathbf{r}_{observed}(\mathbf{q}_i, \mathbf{q}_r, \mathbf{j}) \stackrel{\Delta}{=} F(\mathbf{q}_i, \mathbf{q}_r) \mathbf{r}_0$. We can further assume that $F(\mathbf{q}_i, \mathbf{q}_r)$ is independent of wavelength in a specified range. Therefore, we still speculate that if two spectral vectors $\bar{\mathbf{r}}_1$ and $\bar{\mathbf{r}}_2$ are from the same material class, then we should have $\cos(\bar{\mathbf{r}}_1, \bar{\mathbf{r}}_2) \approx 1$.

However, $\cos(\bar{\mathbf{r}}_1, \bar{\mathbf{r}}_2) \approx 1$ is only a necessary condition for $\bar{\mathbf{r}}_1$ and $\bar{\mathbf{r}}_2$ to be from the same material class even under Minnaert or extended Minnaert assumptions. Two spectral vectors from different material classes may still have $\cos(\bar{\mathbf{r}}_1, \bar{\mathbf{r}}_2) \approx 1$. For instance, dark shadow pixels and bright cloud pixels could have spectral vectors of different magnitudes, but their cosine values could be very close to 1. Therefore, the magnitude of the spectral vectors has to be considered when determining the closeness of two spectral vectors.

In our research, we developed the following spectral angle projection clustering technique. First, we used cosine as a closeness measure to roughly determine a number of principal spectral angles (PSAs). These PSAs may simply represent the vegetation, soil, water and clouds, with only a few major classes or principal classes. Once the PSAs are determined, the entire data set is again classified according to its projections onto the PSAs using a distance-based clustering algorithm. The support argument is: If PSAs are determined through spectral angle (cosine) clustering, then each pixel in the data will have a corresponding main PSA. The projection of each pixel onto its own corresponding PSA would be much larger than its projection onto other non-corresponding PSAs. Therefore, if PSA projection measurements are used for distance-based clustering, it is unlikely that two pixels with different corresponding PSAs would be clustered into the same cluster.

IV. SAP BRDF NORMALIZATION ALGORITHM

The Spectral Angle Projection-based BRDF Normalization algorithm (SAPBN) developed in our project is outlined as follows:

A. Determining Surface Cluster Membership

The strategy for class membership determination consists of two related clustering steps. The first clustering procedure, based on the measure of the cosine of the spectral angles, is used for determining the PSAs. The second clustering procedure is based on the measure of the Euclidean distance of the PSA projected data and is used for class membership determination. The keys of the strategy are the cosine measure in the

original data space and the Euclidean distance in the PSA projection space. Once the land surface class (or cluster) memberships are determined through the previous strategy, multi-angle observations for the same class can be readily calculated using aviation and digital elevation data.

B. Establishing Empirical BRDF Relationship

When multi-angle observations can be made for the same material cluster, an empirical BRDF function can be established for the cluster. This can be accomplished through conventional linear regression of the selected BRDF kernel functions, given the requirement that at least three observations of different geometries can be made for each surface material cluster. The regression will produce three parameters for each material cluster: the coefficients of the isotropic, geometric and the volumetric terms, respectively.

C. Improving Results through Iterative Correction

Once an empirical BRDF function is established for a pixel according to its cluster membership, the reflectance of this pixel can be initially corrected to the calculated or predicted BRDF value using the empirical BRDF function with respect to its geometrical parameters. This correction process is used to reduce the errors not related to the BRDF effect, such as those related to the atmospheric turbulence, aircraft movement and scanner vibration. This correction process may be repeated as needed by: (1) applying the spectral angle projection clustering technique to the BRDF-corrected image and generating the surface clusters, (2) establishing a new empirical BRDF function using the new surface cluster membership information and the original reflectance data and (3) correcting the original data using the newly established BRDF functions.

D. Normalizing BRDF Using Reference Geometry

The last step of BRDF normalization is normalizing the data using the standard, pre-selected reference geometry. Once the pre-established BRDF function is verified as acceptable, the conversion of the data through BRDF functions using standard reference geometry is straight forward.

From the application point of view, BRDF normalization is usually not the end of the image interpretation and analysis; instead, it is the beginning. The number of surface clusters in BRDF normalization, based on which BRDF functions were established, should not be too large or too small. The rule of thumb is that the number of surface clusters should be from two to five times the number of final intended classes for image classification or interpretation. Of course, the BRDF normalization may itself be considered a classification process, but that result should not be assumed accurate.

V. SAPBN SYSTEM PROTOTYPE

A software system for BRDF correction and normalization was prototyped based on the algorithm and procedures above. Fig. 1 shows the flowchart of the algorithm, where solid-line boxes represent the major program modules of the software,

while dashed-line boxes represent the intermediate results or output.

Fig. 1. Processing flow of the SAPBN software system.

The system has seven major components, each of which corresponds to an independent program module. The central portion of the system is the BRDFGUI, which manages and calls other major programs within the system. The major component program modules are:

BRDFGUI – The center GUI piece of the BRDF normalization program. All seven related components of the system are arranged visually in the window of this program.

KERHAND – Computes and queries kernel lookup tables (LUTs) at the user's specifications.

COMPGEO – Computes the incidence-view geometrical parameters from aviation and digital elevation model (DEM) data.

KERMAP – Takes the geometric parameters generated by COMPGEO as input and creates an image with up to four bands, the calculated Ross-Thick, Ross-Thin [7], Li-Dense and Li-Sparse kernel [8, 9] values.

SAPCLUS – Takes the input of a multispectral image and outputs a single-band image with spectral cluster memberships for Spectral Angle Projection Clustering.

KERFIT – Computes coefficients for the empirical BRDF functions (regression).

MODPRED – Computes the predicted (or corrected) BRDF values using the empirical BRDF model established in KERFIT.

BRDFNORM – Takes the pre-calculated cluster information, the BRDF coefficients and user-selected geometric parameters and outputs a geometry-normalized image file.

VI. SUMMARY

After three years of continuous research, a software system capable of performing generic BRDF normalization for multispectral images has been prototyped at the U.S. DOE's Remote Sensing Laboratory. The full function and accuracy of the system is under assessment through appropriate U.S. Department of Energy projects.

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