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Voltar

Using shade fraction image segmentation to evaluate deforestation in Landsat Thematic Mapper images of the Amazon Region

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Abstract. Image segmentation based on the shade fraction of a Landsat TM image was effective in measuring the areal extent of Amazonian deforestation. The shade fraction image derived from spectral mixture models was related to the forest canopy structure. Dense tropical forests have a medium proportion of shade within their canopy while deforested areas (bare soil, pasture, and/or regrowth) have a comparatively small proportion. Comparison of image segmentation results with conventional techniques showed visual agreement. Even though additional tests are necessary to validate this approach for large areas, the technical soundness of the approach has been demonstrated.

1. Introduction

There is a need for continuous monitoring of deforestation in tropical forests due to its impact on climate, biodiversity and soil degradation. Currently used methods to estimate deforestation extent at regional scale are based on the visual interpretation of Landsat TM imagery (INPE 1996, Skole and Tucker 1993) or on limited digital classification based on pixel-by-pixel analysis without contextual information. Many ecological, hydrological and biogeochemical models require high spatial resolution and georeferenced digital data (geographical information system—GIS). This has lead to much visual analysis and hand-digitization. Even though visual interpretation has acceptable accuracy it is highly laborious and costly, especially in areas where small intricate fields such as the ‘fish-bone’ pattern of Rondônia predominate (INPE 1996).

Conventional digital analysis of Landsat TM data based on pixel-by-pixel classification is limited because it takes into account only the spectral variation of the scene, missing the potentially important contextual information of the objects. Fortunately, relatively new approaches using image segmentation have been quite promising for tropical deforestation estimation (Batista et al. 1994, Alves et al. 1996). However, this technique when applied directly to the original Landsat TM spectral information, demands significant computer time (Batista et al. 1994, and further investigation of this work).

Perhaps the most widely used technique to reduce the dimensionality of Landsat TM data, while still preserving most information required for adequate vegetation characterization is the normalized difference vegetation index (NDVI) proposed by Rouse et al. (1973). However, the NDVI has a major limitation for the characterization of deforestation in the Amazon because young regenerating forests tend to have higher NDVI values than mature forest NDVI, while other deforestation classes,
such as pastures or bare soils, have low NDVI values. Therefore, it is very difficult
to design a simple deforestation classification algorithm using NDVI for the Amazon
region. Fraction images based on spectral mixture analysis is another promising

The shade fraction image has been found to be well correlated with vegetation
Structure determines canopy shade content of land cover classes, for instance, undisturbed
tropical forests, usually have medium shade content as opposed to deforestation
classes such as bare soil, pastures, or regenerating forests with low shade content
(Adams 1995).

We present an automated procedure to generate deforestation information including
mapping and area extent estimations, integrated into a GIS database. This
approach based on shade fraction image generated by a spectral mixture model,
followed by region growing segmentation and a per-field unsupervised classification
algorithm is operationally feasible for the Amazon. The validation of the procedure
has been made by comparison with conventional techniques (INPE 1996) for a full
Landsat TM scene in Rondônia, an area which is considered as a spatially complex
as any scene in Amazônia.

2. Study site

Even though the methodological approach proposed in this Letter is envisioned
to apply to the entire Amazon Basin, a complex scene with several small fields of
the typical Rondônia "fish-bone" pattern was selected (figure 1). This area covers
approximately 34,000 km² and is dominated by dense tropical forest. Most of the
deforested area is covered by grassy pastures in land holdings of 100 ha. In smaller
proportions are perennial and annual crops, such as cocoa, coffee, rice and corn in
fields with areas of 200 to 500 ha. Circa 22 to 48 per cent of previously deforested
land has been abandoned and was covered by regenerating forests of different ages
(Alves et al. 1996).

3. Data and procedure

Landsat TM images of bands 3, 4, and 5 from path/rows 231/67 (5 August,
1990—Rondônia) were used. The Landsat TM data were resampled to a pixel size
of 60 m by 60 m resulting in a image size of 3326 pixels by 3072 lines, in order to
reduce computer processing time. Charts at 1:250,000 (Rio Machadinho, FIBGE
1981 and Ji-Paranã, DSG 1982) were used for georeferencing the satellite images.
The GIS software package SPRING (Câmara et al. 1992) with basic functions of
image processing (including 'segmentation' and 'per-field clustering classifier'—
ISOSEG) was used. Results of the PRODES Project (INPE 1996) for the same area
were used for validation of the results of the proposed method.

3.1. Shade fraction image

There are several approaches to determine the fractional proportions of a multi-
spectral image. The constrained least squares method was employed here using bands
-3, -4, and -5 of the Landsat TM to generate the fraction images of vegetation, soil,
and shade within the pixels.

The formulation of the mixture model based on the constrained least squares
method is detailed in Shimabukuro and Smith (1991). The endmembers spectral
signatures were collected directly from the Landsat TM images using representative
targets of green vegetation, soil, and shade. This was done interactively until it was verified that the component signatures were an adequate representation of the mixture components of the area analysed and therefore the constraint equations were strictly true.

3.2. Segmentation

The procedure used for image segmentation was based on the 'region growing' algorithm where a region is a set of homogeneous pixels connected according to their properties (Zucker 1976). A detailed description of the segmentation procedure used can be found in Battista et al. (1994).

The segmentation algorithm was applied to the shade fraction image and the proportion, spatial and contextual attributes of the segments (regions) were acquired to be used in the classification procedure.

Two parameters have to be set by the analyst: (1) similarity: the Euclidean distance between the mean digital numbers (here shade proportion) of two regions under which two regions are grouped together; and (2) area: minimum area to be considered as a region, defined in number of pixels.

3.3. Classification

An unsupervised classification based on a clustering algorithm was applied to the segmented shade fraction image. Clustering techniques are largely known (Duda
and Hart 1973). The algorithm used in this experiment, named ISOSEG (Bins et al. 1993) uses the covariance matrix and mean vector of the regions to estimate the centres of the classes. The analyst can define an acceptance threshold which is the maximum Mahalanobis distance that mean digital numbers (here shade proportion) of regions can be far from the centre of a class to be considered as belonging to that class.

The resulting clusters generated in the previous step are then identified by the analyst either as mature forest or deforestation classes. An accuracy assessment of this new alternative technique is possible by comparison with PRODES results (INPE 1996).

4. Results and discussion

After several experimental iterations of the segmentation algorithm applied to the shade image, the similarity and area thresholds were set to 8 and 25, respectively. They were set after a visual inspection guaranteed that all deforested classes were properly outlined. For the per-field unsupervised classification, the acceptance threshold was set to 99 per cent. As a result, there were only five classes generated by the ISOSEG classifier which made the analyst's job of associating these classes to deforestation classes very easy. Figure 2 summarizes the entire procedure to automatically generate deforestation estimations.

A comparison of the use of the shade image instead of the original Landsat TM bands (-3, -4, and -5) resulted in substantial saving in computer time: the process with the shade image took only 23 per cent (141 hours) of the required time to complete the process with the original bands (611 hours) using a SUN SPARCSTATION-20 with 96 Mbytes for RAM and 270 Mbytes of virtual memory. In addition, the analyst's editing job was much simplified. The generation of the shade image represented less than 2 per cent of the entire process. This same study site required 220 hours of an experienced delineators time to aggregate all deforestation areas from 1978 to 1990 into a single map.

The procedure reported in this Letter, similar to other techniques, requires editing after the digital analysis steps to eliminate some erroneous areas such as drainage pathways, roads, villages, rock outcrops and specular reflections and shadows from mountains and ridges (white areas in figure 2). These undetermined classes represented ca. 2 per cent in area of the full scene, requiring that the analysts label them without having to edit boundaries. Editing to include missed deforested areas were minimum. The reason for the reduction in the editing process is the excellent discrimination between mature forest and deforestation classes using the shade fraction image. By comparison, the conventional approach currently used in the PRODES project requires local adjustments done by manually overlaying the photograph interpretation maps to improve the geometry of the product. In complex areas such as in Rondônia the quality of the georeferencing is very poor due to the large number of small fields to be outlined. Distortions in several directions and misplacement of polygons boundaries are currently a source of error in the PRODES.

5. Conclusions

Pre-processing of the original Landsat TM bands to generate the shade fraction image allowed substantial reduction in the processing time for calculating a deforestation assessment. Results of the segmentation of the shade image followed by a per-field unsupervised classification suggest that this automated procedure for
Excerpt of the geo-referenced color composite Landsat TM image for bands 5, 4, and 3 (R, G, and B), acquired on 08/05/90.

Excerpt of the shade fraction image derived by using the constrained least square method (spectral mixture model) for bands 3, 4, and 5.

Excerpt of the segmented shade image using the region growing algorithm (similarly = 8; area = 25; pixel size = 60 m).

Classification results using ISOSEG on the segmented shade image, compared with PRODES (excerpt and full TM scene).

Figure 2. Steps and results of the automated deforestation estimation procedure applied to the full Landsat TM scene of Rondônia.
deforestation estimation is feasible and a sufficiently adequate technique especially for complex scenes of the Amazon. The approach provides accurate results directly in a GIS format essential to model ecosystem land use and cover change. This is especially important for year-to-year monitoring of deforestation due to the limitation of the visual interpretation approach in complex areas.

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