USING RATIONAL POLYNOMIALS FOR MAPPING IN AREAS WITH TERRAIN WITHOUT USING A DIGITAL ELEVATION MODEL

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Abstract

Illumination effects in satellite images caused by terrain create significant problems for conventional classification. In some studies, simple band ratios have been used, rather than the original bands, to reduce the problem. A wide variety of methods used to correct or reduce the effects are available in the literature. In general, terrain-correction methods require a suitable Digital Elevation Model (DEM). However, a DEM is not always available.

In this paper, we present an approach for discriminating between different classes in terrain-affected areas which does not require the use of a DEM to correct illumination effects prior to the analysis. Instead it includes rational polynomial terms in a canonical variate analysis (CVA) formulation to find vectors that best separate the classes of interest. This approach was used on a terrain-affected test area in Queensland using Landsat TM data for discrimination of woody perennial vegetation from other cover types. The rational polynomial vector was found that best separates the classes of interest. Results achieved showed that the separation of the two classes has been satisfactory. Using the vector found, a set of indices was derived, and used to generate a corresponding woody perennial vegetation map. The map shows good reduction of terrain effects.

Details of the technique and examples of the results obtained will be discussed.

1. Introduction

Discriminating land-cover types in terrain-affected areas of satellite images has been a long-standing problem. The difficulties can be attributed to the illumination effects caused by different slope angles and orientation of the terrain. Analyses of woody perennial vegetation (woody) on terrain-affected areas of Landsat TM data are affected by such problems; areas on slopes that face away from the sun are darker, while those towards the sun are brighter.

Previous efforts in addressing the illumination effects caused by terrain in satellite images include the use of band ratios (Holben and Justice, 1981) and terrain-correction algorithms (Teillet et al., 1982 and Meyer et al., 1993). In a comparison study conducted by MacDonald et al. (2000) to test the performance of the various algorithms for forested areas in New South Wales, it was shown that the C-correction method out-performed the other commonly used algorithms such as the statistic-empirical method, Minaert correction and cosine correction. In general, suitable Digital Elevation Models (DEM) are required when applying the algorithms to data. In another study that compared band ratios and the Minnaert constant (Colby, 1991), the latter method was found to be more superior.

In this paper, we describe an approach to discriminate between different land-cover types using rational polynomial terms in a standard canonical variate analysis. Underlying this approach is the observation that terrain illumination tends to be reduced in displays of ratios of linear combinations of bands as compared to displays of linear combinations of bands. Of interest here is the determination of the band combinations that provide the “best” discrimination of the classes of interest.

This study considers a simple case of discriminating between non-woody cover and woody cover over mountainous terrain (darkly-illuminated and brightly-illuminated slopes) in a test area chosen from the year 2000 Landsat TM data over south-east Queensland, to evaluate the approach in terrain-affected areas without using a DEM. In the following sections, we describe the methodology adopted, CVA that includes rational polynomials, and discuss the results achieved.

2. Methodology

An area of high relief taken from a year 2000 Landsat TM data over south-east Queensland was chosen for this study. Figure 1 shows the area, which consists of mainly non-woody and woody covers on terrain-affected areas.

Training sites were selected across the study area within the classes of interest: non-woody areas, woody areas on darkly-illuminated slopes and woody areas on brightly-illuminated slopes. The purpose of the study is to investigate whether the woody areas (on darkly-illuminated and brightly-illuminated slopes) can be discriminated as a single class from the non-woody areas. A total of 89 sites were selected, 27 from non-woody areas, 31 from darkly-illuminated slopes and 31 from brightly-illuminated slopes.

Figure 1. Test area chosen in this study: bands 5, 4 and 2 assigned to red, green and blue colours respectively. Data is taken from year 2000 Landsat TM scene of south-east Queensland (Eastings: 778940.24E 860030.26E Northings: 7488356.85N 7407790.00N).

CVA with rational polynomial terms

CVA is widely used to analyse group structures in multivariate data, and as a means of separating a group of samples from different populations. Mathematically, it is equivalent to a one-way multivariate analysis of variance. The goals of CVA include

(i) finding a vector that best separates different groups of data

(ii) testing whether the means of those groups along the vectors are significantly different, and

(iii) assigning observations to groups.

The explanation of the theory of CVA and calculations of the various quantities involved can be found in Mardia et al., 1979. In brief, CVA finds linear combinations of the original variables, $y = c^t x$, that maximize the separation between the different groups; here c represents the canonical vector, and x represents the observations. Specifically, the canonical vector, c, is chosen to maximize the canonical root $f = c^t Bc / c^t Wc$, where B and W denote the between-groups and within-groups sum of squares in product matrices respectively. This is equivalent to choosing c to maximize $f = between(y)/within(y)$, where $between(y)$ and $within(y)$ denote the between-groups and within-groups sum of squares respectively.

In the rational polynomial CVA approach, we form the ratio of linear combinations $y = \frac{c_1^t x}{a + c_2^t x}$ where a is a constant, choosing c_1 and c_2 to minimize $-f$, where $f = between(y)/within(y)$. We will refer this method as CVAR. In this study, the minimization procedure adopted to find c_1 and c_2 is the Simplex algorithm (Nelder and Mead, 1965), which we have found to be remarkably robust, and does not require derivatives, albeit at the cost of extra iterations. For computational purposes, a is set to be 1, and the starting values for c_2 are set to zero. Only c_2 is varied in the function minimization; conditional on c_2, the problem reduces to a standard CVA, for which an explicit eigen-solution exists.

3. Applying CVAR to data

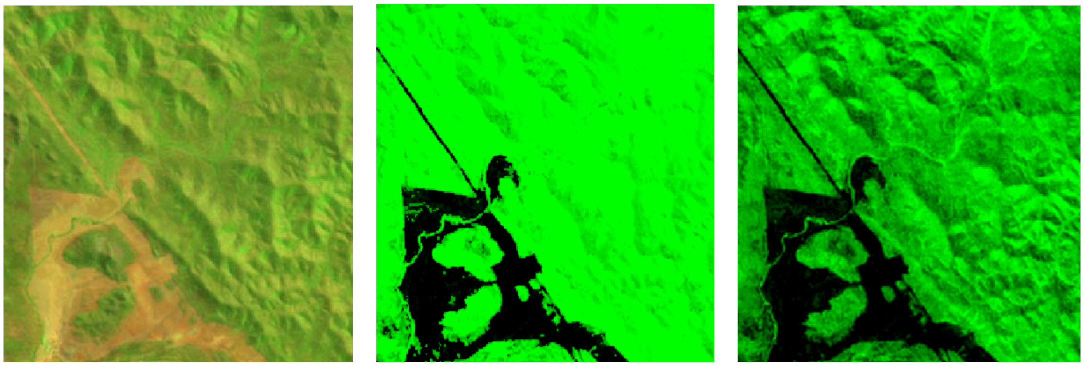
CVAR with a directed contrast was applied to the training data. The main purpose of a directed contrast analysis is to find a vector that best separates two specified classes or groups of classes (the latter are sometimes referred to as super-classes). A directed contrast has the effect of calculating the means for the two classes or super-classes of interest, while retaining the individual classes for the within-class calculations.

In this study, we used the training sites of woody chosen on both the darkly-illuminated slopes and brightly-illuminated slopes of the terrain as a single super-class, and performed a directed contrast analysis on this super-class with the non-woody class. The usual CVA for this directed contrast gave a canonical root of 10.52. The canonical root achieved from the CVAR is 58.8, indicating very good separation between woody and non-woody, and producing a much better separation between the two super-classes under consideration. The vector that was found in the CVA analysis was subsequently used to derive a set of indices, and these indices were used to generate a corresponding woody perennial vegetation map of the study area. Results of the map will be illustrated using two examples in the following sub-section.

3.1 Results and discussion

In Figures 2 and 3, we show two examples taken from the woody perennial vegetation map generated by the CVAR method. Each example is displayed with its corresponding Landsat TM data, and the woody map produced using original CVA for comparison purposes.

In both examples, the map produced by the CVAR method shows a markedly reduced influence of terrain, while most of the terrain effects remain in the map produced by the original CVA method.



(a) (b) (c)

Figure 2. Picture (a) shows the Landsat TM image under study; bands 5, 4, 2 assigned to colours red, blue and green respectively; (b) shows the woody map(expressed as a posterior probability) produced by the CVAR approach, and (c) is the map (expressed as a posterior probability) produced by the usual CVA method. Non-woody areas are represented in black.

(a) (b) (c)

Figure 3. Picture (a) shows the Landsat TM image under study; bands 5, 4, 2 assigned to colours red, blue and green respectively; (b) shows the woody map (expressed as a posterior probability) produced by the CVAR approach, and (c) is the map (expressed as a posterior probability) produced by the usual CVA method. Non-woody areas are represented in black.

4. Summary

An approach has been developed to map woody perennial vegetation for areas including high relief of Landsat TM data. The approach uses rational polynomial terms in a canonical variate analysis to find vectors that best separate specified (groups of) classes while minimising the variation within the classes.

The method was tested using Landsat TM data over a terrain-affected area located in south-east Queensland. The main aim was to separate non-woody areas from woody areas on both sides of the terrain (which appear as dark and bright in the image). The canonical root achieved indicated very good separation of the two groups of classes. A set of indices was derived from the vector found in the analysis and was used to generate a corresponding vegetation map. The map shows good reduction of terrain effects.

Future research will focus on how the CVAR approach performs through time across larger geographic areas.

5. References

Chvatal, V. (1983). Linear Programming. W. H. Freeman, New York.

Colby, J.D. (1991). Topographic normalization in rugged terrain. Photogrammetric Engineering and Remote Sensing, 57, 531-537.

Holben, B.N., and Justice, C.O. (1981). An examination of spectral band ratioing to reduce the topographic effect of remotely sensed data. International Journal of Remote Sensing, 2, 115-123.

Mardia, K.V., Kent, J.T, and Bibby, J.M. (1979). Multivariate Analysis. Probability and Mathematical Statistics. Academic Press, London.

McDonald, E.R., Wu, X., Caccetta, P.A. and Campbell, N.A. (2000). Illumination correction of Landsat TM data in south east NSW. Proceedings of the Tenth Australasian Remote Sensing and Photogrammetry Conference, Adelaide, Australia, August 2000.

Meyer, P., Itten, K.I., Kellenberger, T., Sandmeier, S. and Sandmeier, R. (1993) Radiometric corrections of topographically induced effects on Landsat TM data in an alpine environment, ISPRS Journal of Photogrammetry and Remote Sensing, 48, 17-28.

Nelder, J.A. and Mead, R. (1965). A simplex method for function minimisation. Computer Journal, 7, 308-313.

Teillet, P.M., Guindon, B., Goodenough, D.G. (1982) On the slope-aspect correction of multispectral scanner data, Canadian Journal of remote Sensing, 8, 84-106.