DEVELOPING TASSELLED CAP TRANSFORMATION FOR SPOT HRV REFLECTANCE DATA

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ABSTRACT

Six SPOT HRV images over Wiltshire, England were acquired. All images were atmospherically corrected. DNs were transformed into inherent target reflectance. Bare soils were identified on the images, and correlation equations between reflectances of the three HRV bands were derived by simple linear regression analysis. Two artificial soils data samples were then created according the equations. The Gram-Schmitd process was used to derive the BRIGHTNESS, GREENNESS and the THIRD COMPONENT. It is found that the THIRD component contains less than 5% of the total information. The BRIGHTNESS and GREENNESS created by using two bands (one visible and the NIR) were compared with their equivalent features created by using all the three bands. It is found that the BRIGHTNESS and GREENNESS features of two bands contain less then 90% of the total information.

KEY WORDS: SPOT, Tasselled Cap, Information Content.

INTRODUCTION

Tasselled cap transformation has been widely used in vegetation studies and other applications. The concept of tasselled cap has been explored in details by Kauth and Thomas (1976) and Crist (1984, 1985, 1986). "This transformation is based on the observation that, in agricultural regions, the correlations between the visible bands and between the near-infrared bands of the MSS cause vegetation and soil related information to fall primarily into a single plane. The tasselled cap transformation rotates the data such that a 'head-on' view of the plane is obtained, thus capturing the vast majority of MSS data variation in two dimensions". (Crist and Cicone, 1984). It has been developed and studied in great detail for MSS, TM and TM reflectance factor data. (Kauth and Thomas, 1976, Crist, 1985, Crist and Cicone, 1986). However, "... the expression of the data structures is influenced by sensor calibration and detector response, the transformations are sensor-dependent, i.e., the transformation matrix for MSS can not be applied successfully to TM data."(Crist, 1985). To date, the transformation for SPOT HRV data has not been studied in detail. Jackson (1983) compared the greenness features of SPOT XS with that of TM but no transformation details were given.

In this paper, the tasselled cap transformation matrix for SPOT HRV reflectance factor data was proposed. Six SPOT HRV images were all atmospherically corrected. The tasselled cap transformation was developed using minimun of two soils data points, one vegetation and one senescened vegetation point. Information content of each component was also investigated.

DATA PREPROCESSING AND ATMOSPHERIC CORRECTION

Six SPOT HRV images over Devizes, Wiltshire, England for 1988 and 1989 were acquired. Table1 lists the details of these images.

date	Mar30	May05	Jun21	Jul23	Oct31	Nov25

Table1. Dates of image acquisation.

The March scene was chosen as the standard image, and an extract of 1700*1640 pixels was taken around the study area. All the other images were Geomatched onto the reference image. Atmospheric correction was conducted by using the radiance over a patch of coniferous woodland to derive the aerosol optical thickness. The Rayleigh optical thickness was derived by conventional methods. Details of the correction can be found on SPATIAL DATA 2000 (Ji Chang Yuan and Giles D'Souza, 1991). The following is a brief introduction of the algorithm.

The inherent target reflectance is:

$$R = \frac{(L - Lp)*\pi}{Eg * t(\Theta)} - Renv. \qquad (1)$$

Where: Eg is the radiance on the ground;
t(Õ) is the transmittance;
Renv. is the environmental contribution;
L is the total radiance at sensor;
Lp is the path radiance.

The path radiance Lp consists Lpr and Lpa:

$$Lp = Lpr + Lpa \qquad (2)$$

The Rayleigh path radiance Lpr is calculated with empirical methods, so the aerosol path radiance Lpa is derived as follows:

$$Lpa = \frac{pa*\tau a*Eo}{4*\pi*u} \qquad (3)$$

Where: u is cosine of solar zenith angle,
pa is aerosol phase function,
Eo solar irradiance at the top of the atmosphere.

Once the inherent target reflectance of the coniferous woodland is known, the aerosol optical thickness can then be derived through the following equation:

$$\tau a = \{ L - Lpr - \frac{4u(R-Renv)Egt(0)}{\pi} \} * \frac{4\pi u}{paEo} \qquad (4)$$

Where Renv is the environmental contribution to the refelctance.

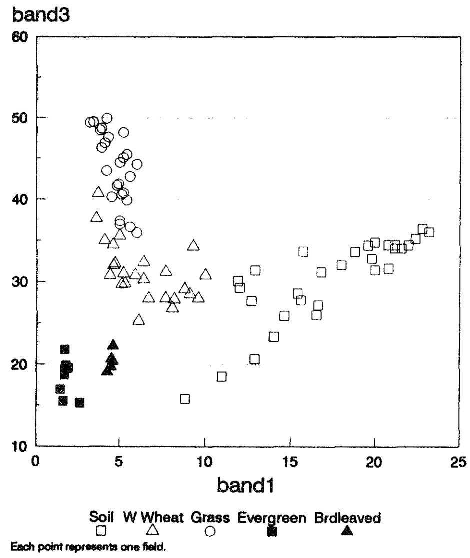
APPROACH

Graphs 1-3 show the plots of the reflectances of one band against another for the data set of March image. It is noticed that the basic shape of the soil line is obvious.

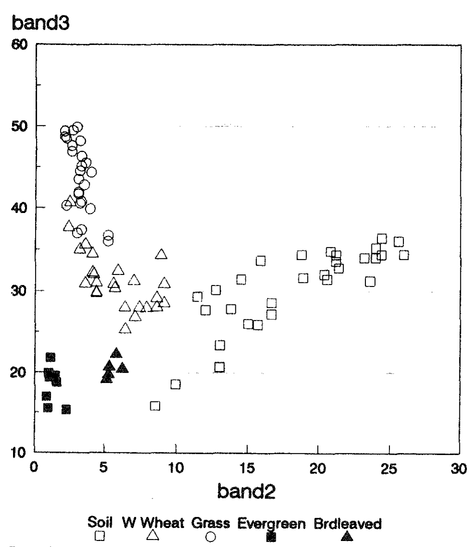
The Gram-Schmitd process is normally used to derive the various planes in the tasselled cap domain. In this paper, Jackson's simple approach (Jackson, 1983) of Gram-Schmitd process with minimum data input was implemented. It requires only two soils sample points, one vegetation and one senescened vegetation point.

However, Jackson (1983) states, "the selection of the soils data points is critical", because the fitted plane of soil will deviate from its actual position if the two data points used are not representative of the whole soils data population. Consequently other planes would be improperly placed since they entirely rely on the plane of soil.

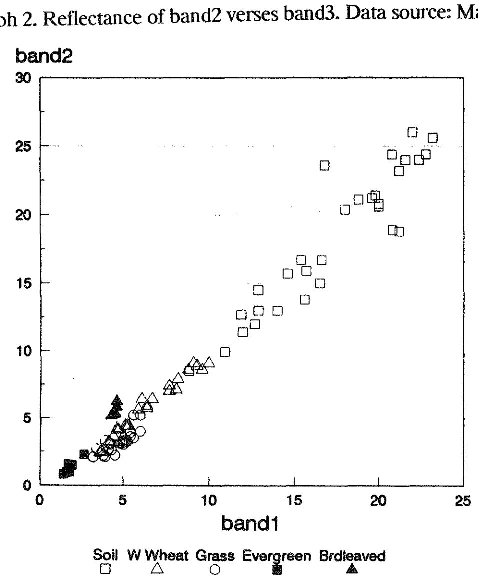
Over 150 soils data points were identified on all the imagesand a simple linear regression for the three bands was determined. The results are shown below:



Graph 1. Reflectance of band1 verses band3. Data source: March30.



Graph 2. Reflectance of band2 verses band3. Data source: March30.



Graph 3. Reflectance of band1 verses band2. Data source: March30.

equations	coef.	S.D
band1 = -2.32+1.07*band2-0.084*band3	0.955	2.04
band2 = 0.26+0.683*band1+0.28*aband3	0.971	2.67
band3 = 17.7+1.31*band1-0.246*band2	0.956	2.12

Table 2. Linear regression analysis.

The idea was that if the correlation between all the bands is high enough, then two artificial soils data points could be created which best represent the soils data population. In this way, the plane of soil can be fixed with confidence.

The correlation coefficients for all the three band combinations are all over 95%. If the reflectance of a soil data point in any band is known, the reflectances in the other two bands can be predicted with over 95% accuracy. Two artificial soil samples were then created according to the regression equations.

To create ideal soil samples, the reflectance of band1 for a dry soil and a wet soil was assumed, the reflectance of band2 and band3 was calculated according to the equations in table2. The refelctance of these two soil samples are shown in tabl 3.

	band1	band2	band3
wet soil	12%	14.11%	23.42%
dry soil	18%	20.30%	30.85%

Table 3. Reflectance of the two ideal soils.

A vegetation and a senescened vegetation point identified on the images were used to derive the GREENNESS and the third component. It was validated that any vegetation point can be used to derive the plane of vegetation and it would make "no difference in the final result" (Jackson, 1983).

The transformation matrix is shown in table 4. Details of the algorithm can be found in Jackson's paper.

	band1	band2	band3
BRIGHTNESS	0.527	0.543	0.653
GREENNESS	-0.420	-0.502	0.756
THIRD	-0.739	0.673	0.037

Table 4. Transformation matrix.

INFORMATION VOLUME OF SPOT TASSELLED CAP

The reflectance factor data of over 300 pixels for each image were transformed into BRIGHTNESS, GREENNESS and THIRD component using the transformation matrix.

To examine the data volume in the new tasselled cap domain, the eigen value of each axis was calculated. Suppose the data set is a multivariate normal distribution, then it can be described as a ellipsoid or hyper-ellipsoid (Ahearn et al 1991). The ellipsoid can be defined by eigen values and eigen vectors of the covariance matrix. The eigen values are proportional to the length of the axes of variation:

$$\text{Length } L = c * \sqrt{é}$$

where: c^2 is the upper (100α)th percentile of chi-square distribution,
é is the eigen value.

The eigen values of all the data sets were then calculated and listed in table5.

date	BRIGHTNESS	GREENNESS	YELLOWNESS
Oct31			
Eigen value	3.46	18.914	0.096
Axes length	5.20	12.158	0.866
(α=0.005)			
Mar30			
Eigen value	9.617	11.098	0.059
Axes length	8.67	9.313	0.679
(α=0.005)			
May05			
Eigen value	9.737	27.103	0.101
Axes length	8.723	14.554	0.888
(α=0.005)			
Jun21			
Eigen value	6.351	12.005	0.800
Axes length	7.045	9.686	1.075
(α=0.005)			
Jul23			
Eigen value	2.867	6.172	0.169
Axes length	4.733	6.945	1.149
(α=0.005)			
Nov25			
Eigen value	13.130	2.766	0.072
Axes length	10.130	4.649	0.750
(α=0.005)			

Table 5. Eigen values and axis length.

Both BRIGHTNESS and GREENNESS capture over 95% of the total variation, while the THIRD component contains less than 5%. It is not surprising because SPOT data is eventually two-dimensional (Kauth and Thomas, 1976; Chavez and Bowell, 1988; Ahearn and Wee, 1991).

The BRIGHTNESS is a partial sum of all the bands used, while GREENNESS shows the contrast between the NIR and visible reflectance. Studies (Crist and Cicone, 1984; Crist, 1984) have shown that the GREENNESS features of MSS and TM are essentially identical between the two sensors, and the BRIGHTNESS features are similar, and when the MIR bands of TM (5 & 7) are omitted, the resulting GREENNESS and brightness features, based on four bands, are both identical to those of MSS. In the case of SPOT data, the GREENNESS and BRIGHTNESS features are different from those of either TM or MSS. This is because there are only three bands and a longer IR band is not available for the SPOT sensor. Secondly, even for the corresponding visible and NIR bands of SPOT sensor, the band widths are different from MSS and TM. Furthermore, studies have concluded that the data space volume of TM 2, 3, 4 data is 70 to 100% greater than that for the SPOT XS data (Ahearn and Wee, 1991), if band 1 of TM is added the data space volume would be even greater. This evidence further illustrates that the greenness and brightness features of SPOT XS data are different from those of MSS and TM. However, similarity of greenness and brightness features between different sensors does occur even with different spectral resolutions as Cicone and Metzler (1984) have proven the indication of analogous brightness and greenness features in data from AVHRR and CZCS. This similarity provides a ready mechanism by which multiple sensors may be used jointly, exploiting the particular desirable characteristics of each. (Crist and Kauth, 1986).

In the MSS tasselled cap transformation, the third component was initially called yellow stuff (Kauth and Thomas, 1976). While in the case of TM, it was simply called the third, or sometimes called wetness (Crist & Cicone, 1984), because it contrasts the middle-infrared reflectance with visible, NIR and the middle-infrared reflectance is most sensitive to soil moisture (Stoner and Baumgardner, 1980). While for SPOT, there is no MIR band available, so the third component in the SPOT tasselled cap domain is perhaps not related to the soil wetness. The third component does not show much variation, therefore this component can be omitted resulting in two-dimensional space data with maximum variation maintained.

COMPARISON OF GREENNESS AND BRIGHTNESS FEATURES OBTAINED FROM DIFFERENT BAND COMBINATIONS

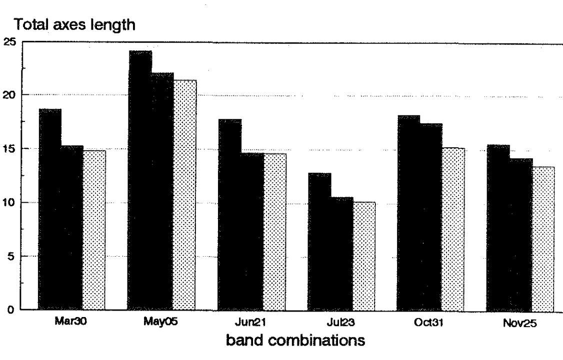
Studies have shown that the two visible bands (band1 and band2) are highly correlated to each other hence many researchers have just used one of the visible bands together with the NIR band to derive various vegetation indices. In this case study, the GREENNESS created with two bands were compared with that derived by all the three bands. The Dynamic Range of GREENNESS is listed in the table below.

bnd cmbinatn	123	13	23
Mar30	40.47	32.45	35.17
May05	54.26	44.96	47.81
Jun21	48.95	40.86	43.49
Jul23	30.48	25.02	27.30
Oct31	36.94	30.04	33.82
Nov25	39.45	30.13	35.54

Table 6. Comparison of the Dynamic Range (DRG) of GREENNESS derived from different band combinations

The GREENNESS derived from all the three bands gives the highest dynamic range. The greenness of band2 and band3 is higher than that of band1 and band3. In general, DRG the greenness derived from band2 and band3 is less than 90% of that of all the three bands, while the DRG of greenness from band1 and band3 is only 83%.

For two-band data, it is not applicable to calculate the "data space volume" (Ahearn and Wee, 1991), hence the total lengths of all the axes were calculated which represent the total information content. (See graph 4).



Graph 4. Comparison of total axes length for different band combinations.

The variation (or information content) of two-band data is about 10% less than the whole three-band data. The variation of data in band2 and band3 is slightly higher than that in band1 and band3 (about 3-5% more). In general, the difference is not significant. The reason is that the two visible bands are highly correlated to each other so that the spectral data in these two bands are redundant. Other studies have also shown that the SPOT data are approximately two-dimensional (Chavez and Bowell, 1988). This concludes that the vegetation indices created by two-band data can be used in many applications without concerning the third band data.

CONCLUSIONS

Tasselled cap transformation for SPOT XS reflectance data was developed. The GREENNESS, BRIGHTNESS and the THIRD component are different from the equivalent terms of MSS and TM data. But the greenness and brightness may be used jointly with those of MSS or TM because of their same inherent nature. The third component only contains a small fraction of information hence can be omitted. Finally, the vegetation indices created from two-band data (one visible and the NIR) can be used in many applications just as those of three band data.

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