Use of the "Tasseled Cap" Transformation for the Interpretation of Satellite Images

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Abstract: *In this paper are treated the aspects regarding spectral enhancement "tasseled cap" applied to the satellite images of medium resolution spatial Landsat 5 Thematic Mapper and Landsat 7 Enhanced Thematic Mapper Plus. The technique is similar to the principal components analysis and suppose the reduction of the data dimension requisite for interpretation of satellite registering. The analysis of the image obtained shows that this can be used on the large area to differentiation of land use.*

1. General aspects

The concept of "tasseled cap" transformation was introduced in 1976 by R.J. Kauth and G.S. Thomas from the Environmental Research Institute of Michigan in the article "*The tasseled Cap -- A Graphic Description of the Spectral-Temporal Development of Agricultural Crops as Seen by Landsat*" published in the paper "*Proceedings of the Symposium on Machine Processing of Remotely Sensed Data"* (Indiana, Purdue University of West Lafayette). In this article the authors have set forth the reasoning underlying the model proposed for Landsat data on agricultural lands and illustrated the spectral behavior of agricultural crops, depending on their stage of development. Originally constructed for understanding important phenomena of crop development in spectral space, the transformation has potential applications in revealing key forest attributes such as species, age and structure (e.g. Cohen et al. 1995).

Essentially, two *tasseled cap* transformations have been developed based on Landsat Thematic Mapper (TM), based on:

- *digital number* (Crist and Cicone 1984);
- *reflectance factor* (Crist 1985).

While the similar spectral characteristics of Landsat 5 Thematic Mapper and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) might suggest direct applicability of both transformations of the images, the latter lends itself to large area applications for two reasons. First, the reflectance factor based transformation was developed based on ground measurements with little atmospheric effects. Therefore, applying this transformation to satellite images requires the respective images to be corrected for atmospheric effects. Although several atmospheric correction algorithms have been developed, for large area applications, there are certain concerns about possible unknown errors that may arise due to lack of or uncertainties in the ground and atmospheric data necessary for running these algorithms. Second, the use of the digital number based transformation in multi-scene applications can be problematic, because changing sun illumination geometry strongly affects the digital number, and thus affects the derived tasseled cap value. Subsequently, a large part of the impact of illumination geometry has to be normalized by converting the digital number into reflectance. Therefore, a reflectance-based transformation is more appropriate for regional applications where atmospheric correction is feasible.

The tasseled cap converts the six highly correlated spectral bands in six new bands arranged almost orthogonally. Most of data variance is concentrated in the first three bands, while the noise and atmospheric effects are concentrated in the last three bands (Kauth and Thomas 1976, Crist and Cicone 1984 a, b).

2. Principals Components Analysis and "tasseled cap" transformation.

The analysis of principal components may be a means of inspiration and guidance for specific tasseled cap transformations. This generates new variables such as the weighted sums of the digital numbers of different bands. In general, most of the information contained in the data recorded is concentrated in the first components, and components higher than three are usually considered as lacking information.

The weighting operations used in the analysis of the main components are statistically determined based on the data used and it has been ascertained that the first principal component corresponds to approximately equal weights, which means that the data fall along the diagonal when the digital numbers from the bands are represented together.

The analysis of principal components consists in transforming data into a new system of coordinates with mutually orthogonal axes, result that can also be attained by applying the tasseled cap transformation. The latter is based on the method of principal component analysis combined with empirical observations.

In theory, the "*tasseled cap*" transformation is a work procedure facilitating the in-depth interpretation and study of satellite data, aiming at reducing the amount of data layers (dimensionality). In essence, the procedure uses mathematical equations to transform a number of multispectral bands (*n*) into a new *n*-dimensional space.

In practice, the procedure is based on a linear transformation of data from the original image into three new axes which become features of the transformation and may be described as follows:

- *brightness*, capable of changing the total reflectance and the physical processes affecting it, so that the new image shows surfaces with little or no vegetation;
- *greenness*, responsible for the enhanced absorption in the visible specter caused by plant pigments including chlorophyll and by the high reflectance in infrared due to the internal structure of leaves. By way of consequence, areas with vegetation shall obviously shown in green;
- *wetness*, defining the "*soil plan*" and represents the primary feature.

In the feature space graphic representation shows a triangular distribution with modifications throughout the vegetation season; the pixel reflectance representing the vegetation moves from soil level towards the top of the triangle and then returns to soil level.

Weights of the "tasseled cap" transformation of Landsat MSS data
(according to Kauth and Thomas, 1976)

Table 1

Components	Band 1	Band 2	Band 3	Band 4
Brightness	0,433	0,632	0,586	0,264
Greenness	- 0,290	- 0,562	0,600	0,491
Yellowness	- 0,829	0,522	- 0,039	0,194
"Non-such"	0,223	0,012	- 0,543	0,810

In the specialty literature this transformation is separately treated for Landsat data taken with different sensors. Thus, for the data recorded with Landsat MSS, researchers R. J. Kauth and G. S. Thomas (1976), established four components, namely *brightness*, *greenness, yellowness* and the "*non-such*" component, as well the corresponding percentages (tab. 1). Later, Crist and Cicone (1984) have adapted the "*tasseled cap*" transformation to the six bands of the Landsat TM data, establishing new percentage values for only three components, i.e. brightness, greenness and wetness, the last replacing yellowness (tab. 2).

Weights of the "tasseled cap" transformation of Landsat 5TM data
(according to Crist şi Cicone, 1984)

Table 2

Components	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Brightness (R)	0,3037	0,2793	0,4343	0,5585	0,5082	0,1863
Greenness (G)	- 0,2848	- 0,2435	- 0,5436	0,7243	0,0840	- 0,1800
Wetness (B)	0,1509	0,1793	0,3299	0,3406	- 0,7112	- 04572

As a rule, the first components contain most of the information, and therefore the *four bands* of the Landsat MSS images or the *six* Landsat TM *bands maybe reduced to the first three principal components*. In some specialty works, in the case of Landsat TM data a fourth component, namely "*fog*" is introduced and coefficients are different. Unlike many other linear transformations used in remote sensing, the coefficients used for operating the tasseled cap transformation are *predetermined* and *not derived* from the set of data.

3. Material and method

The "tasseled cap" transformation has been applied to a subset image from an Landsat 5 TM image taken on August 18, 1989 that included the area between the Piatra Craiului and Bucegi Mountains (Bran-Rucăr gorge). The original image, having a 30 m spatial resolution, was in RGB 432 combination (fake color) in which vegetation is shown in red. The image was geologically framed within the UTM system (Universal Transverse Mercator, North, Zone 35) by means of "*the nearest neighbor*" method, so that the original digital number remained unchanged.

The method used was the "tasseled cap" transformation, which made it possible to enhance the spectral image. The processing was performed by using the six bands of the image, excluding the thermal band.

The image has been edited using the program Erdas Imagine 8.6.

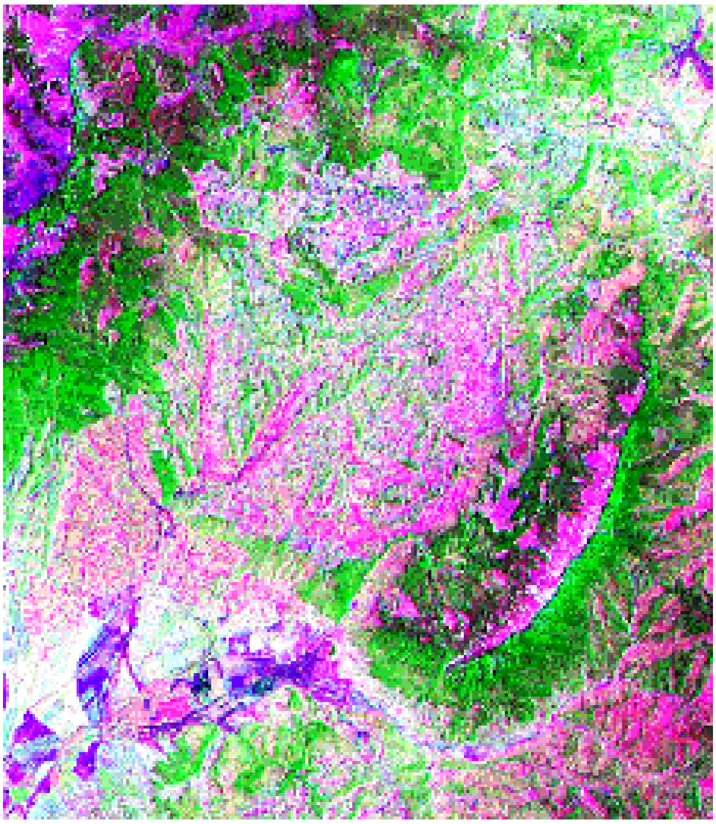
4. Results achieved

The "*tasseled cap*" transformation was applied to the Landsat 5 TM image for six bands and generated six layers of which the first two are the most important as they contain most of the information (95-98%):

- *soil brightness index* (SBI) which showed bare areas, such as regeneration class, agricultural fields, etc. Data relating to bare soil varies according to the type of soil and the incidence angle of incidence under which the sun rays meet the surface of the land;
- *green vegetation index* (GVI) which is an indicator of vegetation status.

The combination of several layers resulted following the "*tasseled cap*" transformation, highlighted several additional features of forest vegetation. Thus, the use of the soil brightness and green vegetation indices shown above together with band 4 (close infrared) makes it possible to separate vegetation during the classification process. The last step of the process consisted in merging the five layers in one image, operation performed by means of the ERDAS program, using the *Layer Stock* algorithm. The five layers used consist of:

- PC1 from Landsat 5 TM, bands 1, 2 and 3;
- 4 TM band 4;
- PC from Landsat 5 TM, bands 5 and 7;



a.

b.

Plate 1. Merging of the Landsat 5 TM image taken in '89:
a - RGB 234 combination; b - RGB 235 combination

- soil brightness index (SBI);
- green vegetation index (GVI).

RGB 234 and *RGB 235 combinations* are the most representative obtained following the merging of the layers set forth above (plate 1 a, b). The following results were obtained following the analysis of the images:

- *for both of the combinations* above, it is possible to separate the forest vegetation (shown in green) and the herbaceous carpet (shown in red), yet no clear-cut distinction between beech tree and mixed coppice can be made (plate 1). In their turn, spruce tree coppice, shown in dark green, can be highlighted within certain limits;
- *RGB 234 combination*, resulting from the merging of layers 2, 3 and 4 above, is less suggestive, as mixed coppice woodland, located on sunny sides can be mistaken for pastures or hay land, because of the poor consistency on certain surfaces (plate 1 a);
- *for the RGB 235 combination*, obtained from layers 2, 3 and 5, such mixed coppice woodland is relatively easier to separate as it is shown in violet, whereas the hay land and the pastures are shown in red.

Considered as a whole, the combinations of different layers resulting in their turn from other spectral processing ensure an enhancement of the performance levels in the interpretation of Landsat 5 TM images.

*The RGB 123 combination***,** resulted following the operation of a "*tasseled cap*" transformation using the first three bands proved to be particularly useful (plate 2). With this combination *spruce tree coppice,* shown in *blue,* can be best separated from *mixed coppice woodand* and it is also possible to clearly identify the *barren and* open *plots of land*, the quarry in Prapastiilor Valley and Grohotis area, *shown in bright red,* the same as uncultivated cropland. The different hues of blue are given by the spruce tree coppice on shady or/and poor consistency slopes.

The differentiation on average spatial resolution satellite images Landsat TM and ETM+ between forests and agricultural crops may be performed in the third tasseled cap TM dimension called *wetness*. In the *greenness/ brightness* projection there may appear some separation between forests and agricultural crops, with a specific localization of the data of the forest, whereas in the *greenness/wetness* projection the separation is clear, being well highlighted in the composite color images.

The differentiation based on the wetness index between forests and other crops consists in the fact that the shading phenomenon is significantly stronger in coppice as compared with agricultural crops or grassy land. Kimes et all have shown that, whereas relatively thick coppice tend to behave similarly to agricultural crops or grassy land with relation to the incidental radiation spread phenomenon, in the case of less thick coppice, characterized by the existence of several empty spaces, the low-frequency transmission occurrence is increased, this resulting in the amplification of the shadowing phenomenon and in the increase of the shadow percentage in the field of vision of the sensor. Moreover, any thinned out coppice containing a considerable percentage of visible trunks, as compared to agricultural crops leads to an increase in the occurrence of projected shadows both in the sublevels of the coppice and on the leaves or pins from the crown canopy of the trees.

The consideration of the shadowing phenomenon as the main cause of the different spectral behavior in the wetness component is supported both theoretically and practically. The inverse relation between radiation spread and wavelength suggests that surfaces lighted up only by the diffuse radiation may receive relatively more light in the visible and close infrared specter rather than in medium infrared (SWIR), which leads to values of the wetness component higher than could be noted in directly illuminated identical surfaces. As for the practical aspect, the simulation of the

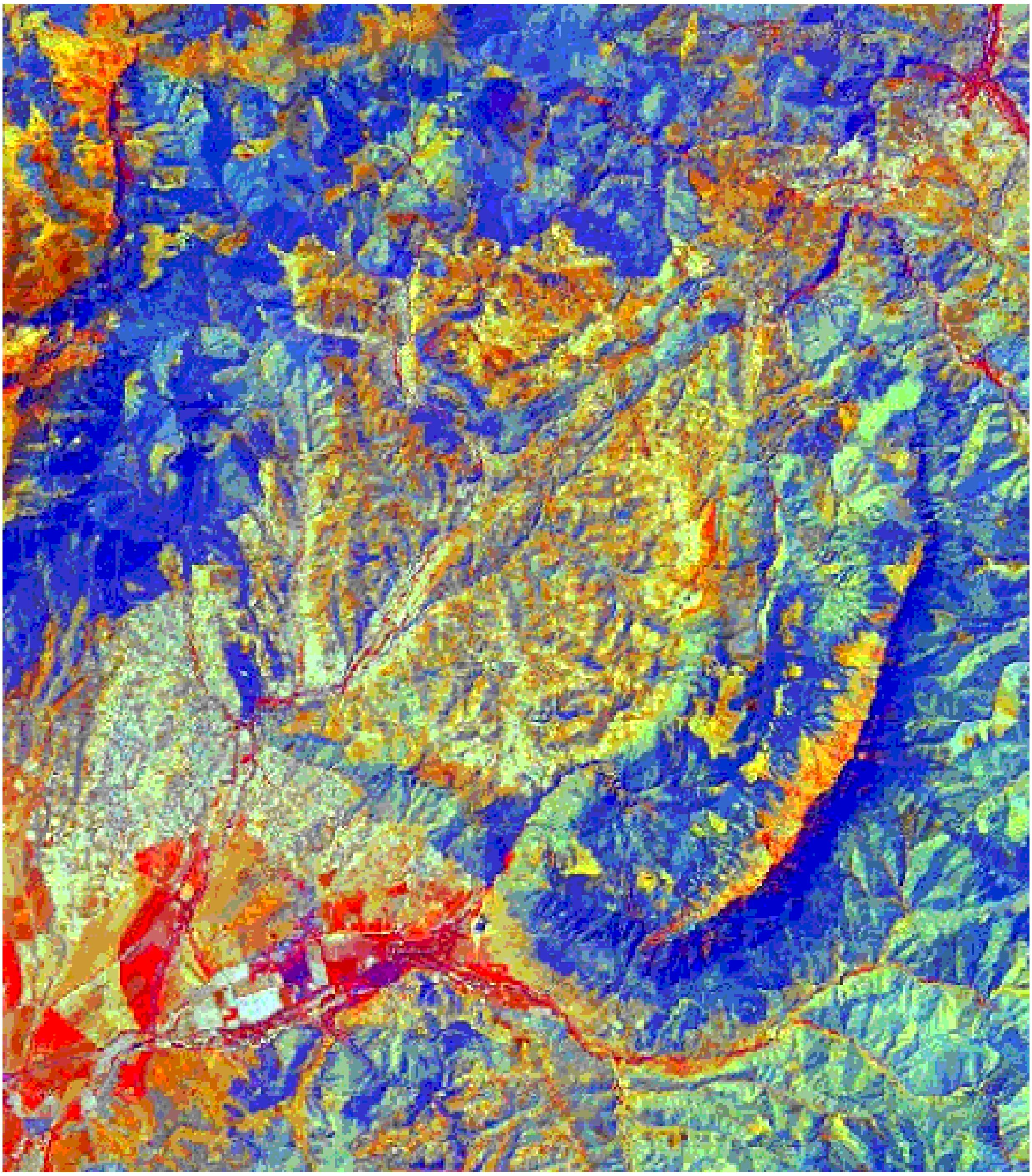


Plate 2. Landsat 5 TM image taken on August 18, 1989 following application of the "tasseled cap" transformation. The image is in the combination RGB 123. Conifers are shown in bright blue, deciduous trees in green-white and the mixed vegetation in combinations of the two colors. Barren fields, unproductive lands (rock, detritus and boulder) and uncultivated cropland are shown in different hues of red.

sensor signals using reflectance panels set within the range 0,4-2,5 μm, determines the tasseled cap values originating from "shadow-like" panels to be placed at the end of the raw of TM data simulated the same way as in the case of agricultural crops and soil reflectance.

In the specialized literature it is shown that there is a high sensitivity to shadow in the first three principal components the coefficients of which are identical with the wetness component from the TM tasseled cap transformation. Moreover, in the case of the wetness feature, the shadowing due to clouds captured in the TM tasseled cap images cannot be distinguished from the shadow caused by coppice. *The differentiation between forest, agricultural crops and grassy lands in the wetness component is due mostly to shadowing.*

5. Conclusions

Considering the results set forth above, the tasseled cap transformation proved to be a reliable and convenient method of *reorientation of Landsat TM* data, so that the information on vegetation and soil be easier to extract, display and understand. Applied to any scene, the transformation produces directly comparable invariant features, for example between scenes or sensors.

In the feature space of the tasseled cap transformation, information on the *type of vegetation, conditions and stage of development* thereto, as well as information on the *type of soil* and *wetness* may be highlighted. Which is more, the estimate of the atmospheric conditions may be carried out from the data used, with a minimum impact in terms of differences in the spectral responses of various categories of land.

Following the research conducted, the "*tasseled cap*" transformation applied to Landsat 5 TM satellite images proved to be useful in separating the different categories of land on larger areas, according to their use. Within the RGB combination, brightness, greenness and wetness, respectively, the various categories of land are differentiated in the image as follows: surfaces with little or no vegetation are shown in red, those with vegetation in green, while damp land appears in blue. Considered as a whole, this transformation allows a clear-cut distinction between and identification of coppice, highlights significant consistency variations and precisely indicates the limits of use categories of the lands, based on colors and hues. The most conclusive and clear results have been obtained by making various combinations of certain spectral bands with the soil brightness and green vegetation indices as well as various principal components. Said combination can actually be made for the purpose of separating various categories of use of the land on a larger area.

Mention is made that neither the tasseled cap transformation nor any other transformation can generate information that is not present in the original data. However, by grouping data variability in the closest components, so that direct association be the result of the spectral answer of the details and physical features of the scene, the tasseled cap transformation applied to Landsat TM satellite images makes it considerably easier to extract information contained in the multidimensional and multispectral images.

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