EVALUATION OF SOLAR ANGLE VARIATION OVER DIGITAL PROCESSING OF LANDSAT IMAGERY

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ABSTRACT

The objective of this work is to evaluate the effects of the seasonal variation of illumination over digital processing of LANDSAT image. For that, two sets of LANDSAT data referring to the orbit 150 and row 28 were selected with illumination parameters varying from 43° to 64° for azimuth and from 30° to 36° for solar elevation, respectively. IMAGE-100 system permitted the digital processing of LANDSAT data. Original images were transformed by means of digital filtering (VARIHV and MD5FIL filter types) so as to enhance their spatial features. The resulting images were used to obtain an unsupervised classification of relief units. After defining relief classes, which are supposed to be spectrally different, topographic variables (declivity, altitude, relief range and slope lenght) were used to identify the true relief units existing on the ground. The samples were also clustered by means of an unsupervised classification option. The results obtained for each LANDSAT overpass were compared. They showed that digital processing is highly affected by illumination geometry. They also demonstrated that, in this study area, there is no correspondence between relief units as defined by spectral features and those resulting from topographic features.

1. INTRODUCTION

These are preliminary results from a research program whose main objective is to evaluate the effects of scene illumination geometry over LANDSAT image digital processing.

The first task of this paper is to evaluate the effects of solar elevation and solar azimuth angles over topographic mapping by digital processing techniques.

The identification of relief units by means of digital processing is a very intricate task since those units are better discriminated by their spatial features (texture) than by their spectral properties.

Digital processing of spatial features requires quantitative definition of the image texture. Tonality and texture are visual concepts that can help the perception and the identification of objects on remote sensing imagery. Tonality refers to surface brightness, whereas texture gives roughness impression resulting from tonal variation within an unit area. The photointerpreter when analysing a photography uses those two concepts simultaneously to identify terrain features. According to Irons and Peterson (1981), the transference of those concepts to digital processing requires a quantitative approach to the visual concepts. Although quantitative information is not directly available in the image as the tonality, there are some digital processing techniques that can transform digital numbers into textural information.

The enhancement of textural features can be obtained by means of digital filtering whose main objective is to highlight some special aspects in the image.

Considering textural features as a function of edge frequency (Iisaka et al., 1978), and assuming that edge frequency depends on the tonal distribution within the image, one can expect that images taken at different illumination geometry will present different results when submitted to the same digital processing, since this geometry interferes in the shadowing pattern.

2. TEST SITE

To test the effect of solar illumination geometry over digital filtering and relief digital mapping, Paraíba Valley was chosen as test site due to the following aspects:

a) availability of topographic data so as to obtain true topographic units map over the region;
b) topographical variability which can enhance solar geometry effects (Figure 1).

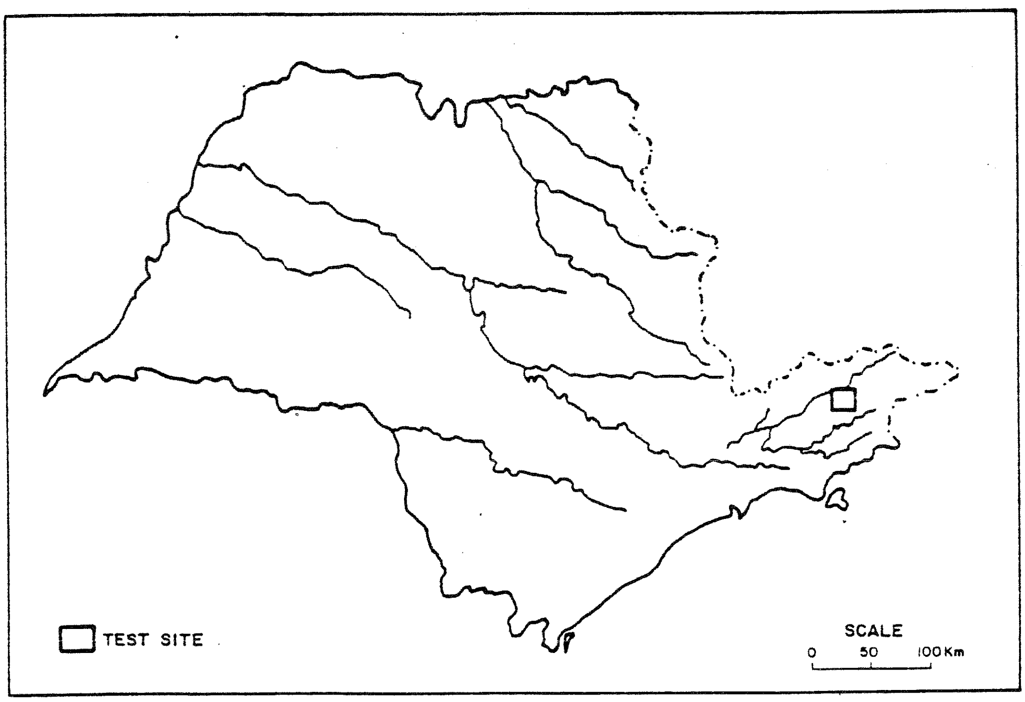

Fig. 1 - Test site location within São Paulo State.

3. METHODOLOGY

a) Data Selection

Considering that the objective of this study was to evaluate illumination geometry effects over digital processing, two sets of LANDSAT data referring to orbit 150, row 28 were selected, with variation in both, solar angle elevation and azimuth (Table 1).

TABLE 1

MSS/LANDSAT DATA AVAILABLE

DATE	SOLAR ELEVATION	SOLAR AZIMUTH
JULY	30^o	43^o
SEPTEMBER	36^o	64^o

Although it had been desirable to compare LANDSAT data referring to July and December so as to maximize solar geometry differences, image quality constraints led to the selection of September overpass.

b) Relief classification by digital processing techniques applied to MSS/LANDSAT data

To classify relief units by digital processing, the original LANDSAT image was submitted to digital filtering, in order to transform spectral information (tonality) into spatial information (texture), as relief is closely related to it.

The main assumption to perform the digital mapping of relief was that topography variation modulates gray level distribution in each LANDSAT spectral band, not considering, of course, spectral variation related to the ground features. If it were possible, by means of digital filtering, to generate a new image where areas with different edge frequency were related to specific gray levels, it would be possible to use this new image to classify relief units.

Among the digital filter types available at the Laboratory for Image Digital Processing (LTDI) in the Instituto de Pesquisas Espaciais - CNPq/INPE, the "variation operator" defined by Dutra (1982) was selected. This type of filter produces for each 3 by 3 pixels regions an output image where digital number value is proportional to relief roughness. This operator is easily applied to the original image through the VARIHV program available at the LTDI. This operator produces an output image where smooth areas (low spatial frequency) are related to dark gray tones and rough areas are related to light gray tones.

Considering that the output image presented a very high edge frequency which increases the variance within each spectral band making it difficult to define relief units, a smoothing filter on the output image was also applied.

As the filtering process generated a large number of new images, those which did not give good relief units discrimination in a visual inspection of the output image at the I-100 display were rejected.

After selecting the types of digital filter to transform texture classes of information into tonal classes of information, the set of new images were applied to carry out an unsupervised classification based on K-Means algorithm.

The typical procedure for digital classification of relief units is summarized in Figure 2. This procedure was applied to both LANDSAT data sets. The resulting classes were named as "spectrally defined relief units" (E.R.U.).

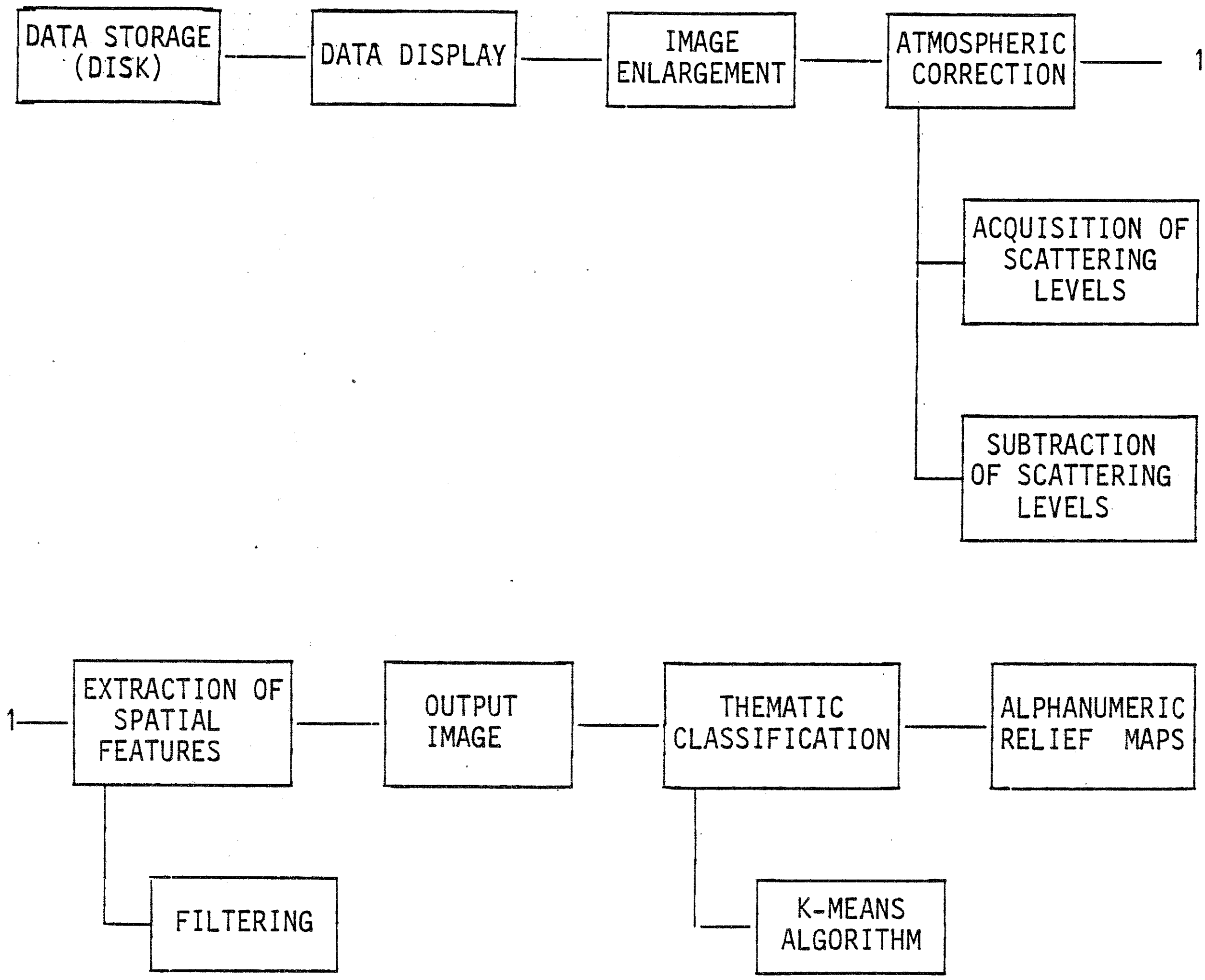

Fig. 2 - Typical procedure to perform digital classification of relief units spectrally defined.

c) Relief classification based on topographic variables

The topographic variables selected to characterize relief units were: declivity, altitude, relief range and slope length.

To measure those variables, topographic charts at the scale of 1:50.000 were used. Topographic data were collected on a grid sample design, for each 0,25 km² on the ground. The resulting data were used as input to perform an unsupervised classification based also in the K-means algorithm. The resulting classes were named as "topographic relief units" (T.R.U.).

d) Comparison between E.R.U. and T.R.U.

The maps resulting from digital processing of MSS/LANDSAT data for both months (July and September) were compared to that obtained from topographic variables. They were overlayed by a grid sample system so as to compute the number of samples belonging to each T.R.U., which were classified in all E.R.U. for both overpasses.

The resulting data allowed to organize tables where the percentage of samples misclassified was estimated.

4. RESULTS

The number of relief classes resulting from digital processing did not vary from July to September. However, if the illumination geometry did not affect the number of classes, it strongly influenced their spatial distribution and shape.

This can be seen from the comparison between Tables 2 and 3, where in the columns on can see the percentage of samples belonging to a single topographic relief unit (T.R.U.) that was classified in different relief units resulting from digital processing of multispectral LANDSAT data (E.R.U.).

TABLE 2

PERCENTAGE OF SAMPLES FROM TOPOGRAPHIC RELIEF UNITS CLASSIFIED IN EACH SPECTRALLY DEFINED RELIEF UNIT - JULY

T.R.U. \ E.R.U.	A	B	C	D	E	TOTAL
1	18%	9%	5%	3%	65%	100%
2	20%	61%	15%	-	4%	100%
3	47%	36%	17%	-	-	100%
4	26%	49%	18%	-	7%	100%
5	58%	31%	-	-	11%	100%

TABLE 3

PERCENTAGE OF SAMPLES FROM TOPOGRAPHIC RELIEF UNITS CLASSIFIED IN EACH SPECTRALLY DEFINED RELIEF UNIT - SEPTEMBER

T.R.U. \ E.R.U.	A'	B'	C'	D'	E'	TOTAL
1	51%	35%	8%	3%	3%	100%
2	8%	36%	24%	16%	16%	100%
3	-	35%	16%	45%	4%	100%
4	-	15%	18%	32%	35%	100%
5	-	28%	32%	40%	-	100%

By analysing Table 2, one can conclude that there is no correspondence between those relief units obtained from topographic chart (T.R.U.) and those from digital processing of multispectral LANDSAT data taken for July. T.R.U. number 1, for instance, belongs, in different proportion, to all the five E.R.U. The same situation occurs in relation to E.R.U. determined by digital processing of LANDSAT data taken for September.

The effects of solar geometry over E.R.U. can be evaluated by comparing Table 2 and 3. While E.R.U. resulting from July overpass (low solar elevation and azimuth angles) presented in the best case 65% of samples clustered in a single T.R.U., data from September overpass only clustered 51% of the samples in a single T.R.U. class.

By analysing the tables one can conclude that classification performance presented by July overpass was better than that showed by September overpass, where samples from all topographic units are equally distributed among different spectrally defined relief units. So, using September overpass is almost impossible to associate at least one true topographic unit to the classes resulting from digital processing of multispectral data.

Considering that, digital processing was similar for both overpasses, classification performance from one set to the other can be atributted to variation in the illumination geometry.

The physical aspects of the study area can also explain the results.The study area is characterized by plains elevated at different heights and oriented according to N50°E. These high plains are dissected by Paraība river tributaries that run perpendicularly to that direction. The interaction between this topographic framework and the illumination geometry criates a completely different shadowing pattern for each LANDSAT overpass.

By analysing Figure 3, one can verify that during July overpass, solar rays hit perpendicularly the valley walls, whereas in September illumination direction changes to an oblique incidence in relation to the valley walls. In those circunstances, assuming a constant slope for valley walls, one can expect that slopes facing sun would present higher radiance values on July overpass.

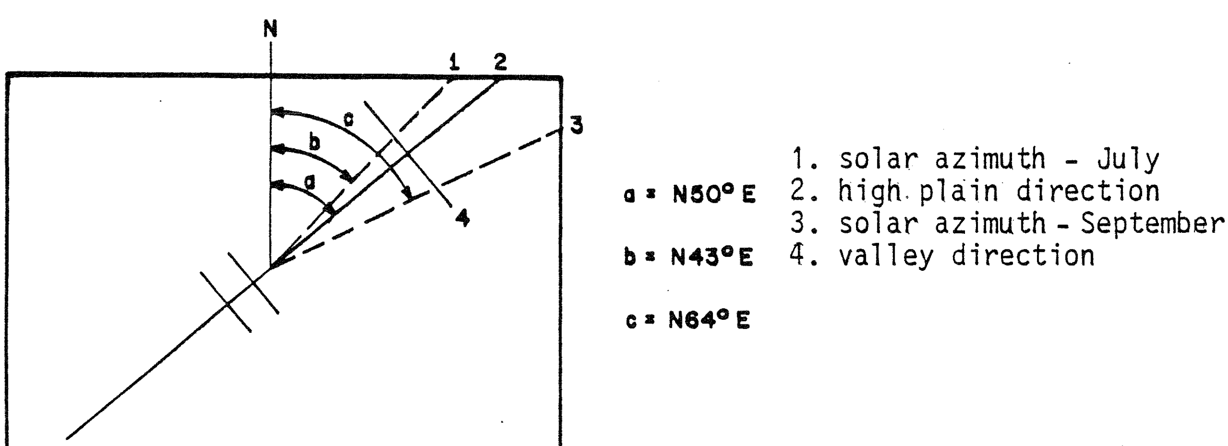

Fig. 3 - Relationship between relief directions and illumination direction.

However, for LANDSAT data elevation angle varies with azimuth angle. So, the above supposition does not apply to the data.

Kowalik (1981) observed that topography affects the radiance according to cos α term. This term traduces the angle between sun vector and the normal to the topographic surface.

Assuming an average slope of 18^o and a surface orientation of $N50^oE$ and $N230^oE$, one could verify that tonal contrast between shadowing slopes and illuminated slopes was greater for September overpass.

This can be better understood considering Slater (1980) reasoning. According to the author, the following angles must be considered to explain surface radiance in irregular topography:

θ = angle of incidence,
θ_Z = zenith solar angle,
α = angle between the surface normal and the zenith.

For an irregular surface, the maximum irradiance is given by:

$\theta = 0$ and $\theta_Z = \alpha$

and the minimum irradiance is given by:

$\theta_Z + \alpha = \theta > 90^o$.

Considering a slope angle of 13^o and solar elevation varying between 30^o and 36^o, from July overpass and September overpass respectively, it happens the situation illustrated on Figure 4.

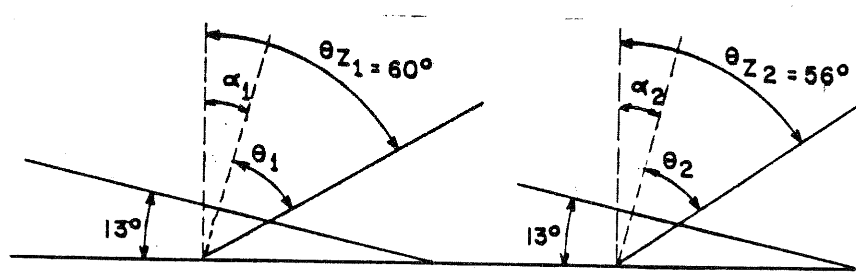

Fig. 4 - Angular variation of θ and θ_Z according to sazonal variation of MSS/LANDSAT data.

The analysis of the Figure 4 shows the following situation:

July		September
θ_1	>	θ_2
α_1	=	α_2
θ_{Z_1}	>	θ_{Z_2}
$\theta_{Z_1-\alpha_1}$	>	$\theta_{Z_2-\alpha_2}$

If maximum irradiance is given by $\Theta = 0$ and $\Theta_Z = \alpha$, one can conclude that it occured in those slopes oriented to N64°E and the biggest tonal contrast is given by September overpass.

The study area is characterized by slopes with declivity varying from 5° to 35°, so the $\Theta_Z - \alpha$ term will vary from one pixel to another in both MSS/LANDSAT sets. In relation to the slope orientation, the study area is characterized by three main directions: N315°E to N360°E; N45°E to N90°E and N215°E to N270°E. Taking in account that LANDSAT imagery used to perform relief units classification presented solar azimuth varying from N40°E to N90°E, one can conclude that the main effect over surface irradiance would be determined by the term $\Theta_{Z-\alpha}$ resulting from the relationship between slope inclination and solar elevation.

5. CONCLUSION

From previous discussion one can verify that is very difficult to evaluate the separated effect of solar elevation and solar azimuth angles over LANDSAT image radiance because there is no condition to fix one variable to study the other. Those angles increase and decrease simultaneously. Besides that, the radiance values depend on the interaction between incident flux and terrain whose declivity and orientation are extremely variable. So, a certain type of angle combination that enhances topographical aspects in a certain region hides them in another.

For digital relief classification high tonal contrasts tend to hiden major topographic units contacts, which can explain the poor classification performance of September overpass.

The results also showed that in this particular study area, there is no correspondence between relief units defined by spectral features and relief units defined by topographical aspects. Further studies must be done to lead a mores satisfactory approach for digital classification of relief units.

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