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Abstract: This paper is designed to give an overview of remote sensing imagery, the kind of information that it contains, and the techniques needed to use it. Given the breadth of the subject, we have limited this paper to the digital analysis of satellite imagery. Fields such as aerial photography and photo interpretation are not covered.

I. – Structure of digital remote sensing imagery

The main difference between aerial photographs and radiometer-generated satellite images is that the latter are based on two types of information sampling:

– **spatial sampling**: the zone under observation is broken down into elementary surfaces or pixels, whose size is determined by the resolution power of the satellite;
– **digital sampling**: the analog signal recorded by the detectors is coded with integers between 0 and 225.

A digitized image is thus a two-dimensional array (**Figure 1**). A SPOT image of 60 × 60 km with a pixel size of 20 × 20 m corresponds to a picture of 3000 lines × 3000 columns. In order to obtain different information, the sensors are multispectral: they use several wavelength bands to observe the Earth.

A multispectral image thus includes several pictures, each one corresponding to a satellite band (**Figure 2**). A multispectral SPOT image, for example, consists of three superimposed pictures and each pixel is associated with three radiometric values between 0 and 255.

The distribution of digital values of all the pixels of an image can thus be visualized through a histogram. In the case of a single band, the histogram represents the frequency of each of the values obtained in this band (**Figure 3**). In certain cases, a bidimensional histogram based on two main bands of an image is used.

II. – Parameters influencing the contents of remote sensing imagery

The contents of remote sensing imagery are strongly linked to certain parameters determined by the characteristics of the satellite.

1. Image definition

The size of subjects studied must be much larger than that of the pixels, which explains the importance of the spatial resolution of the satellite. For crop inventories, areas with an average field size of 1 ha cannot be studied with Landsat MSS (pixel size 0.5 ha).

2. Available bands

The radiometric values of a pixel depend on its optical properties. In the case of a pixel of vegetation, the response in visible bands (green and red for SPOT) is determined by the leaf pigment content, in the near infrared (NIR) band by leaf structure, and in the medium infrared (MIR) by water content. Each band provides specific information on the nature of the body observed. A pixel is characterized by its radiometric values in different bands, which constitute its spectral signature (**Figure 4**). Different types of pixels may at certain periods have similar spectral signatures. This sometimes occurs for soybean and maize crops, in which case it is important to use images taken on carefully selected dates.

3. Date of image acquisition

The date of image acquisition should be related to the subject at hand and this requires good field experience. The date is particularly important when working with rapidly changing subjects, such as agricultural crops. In France, for example, a spring image will contain useful information on barley, wheat, rapeseed, etc., and an image recorded in the fall will provide better information on crops such as maize, sunflower, soybean, etc. In most cases, it is even necessary to have two images taken on different dates to distinguish between certain crops.

The revisit capability of a satellite is therefore of significant importance: every 16 days for Landsat TM and less than 3 days for SPOT due to its side-viewing capability.

III. – Processing of satellite data

The methods used to extract useful information from recorded data vary according to the available infrastructure. An image can be reconstituted pixel by pixel on a photographic medium or kept it in its digital form on magnetic tapes or disks. The paper prints are analyzed using photo interpretation techniques while digital data are processed with computer support using special software.

1. Photo interpretation

We will not deal here with the principles of photo interpretation, as this technique has been commonly used for aerial photographs. It continues to be widely used in the interpretation of satellite imagery, for which it has certain advantages.

An experienced analyst with knowledge of the subject and terrain can interpret an image with its different aspects on the basis of color, tone, shape, structure, and relative position of its components, and by eliminating noise (undesirable data). The analyst also draws on past experience to consider general information on geology, pedology, climatology, etc., not contained on the image. The quality of the interpretation of such images thus depends first and foremost on the competence of the analyst. Area estimation for different crops or formations, however, remains a long and tedious task when precision is needed.

In general, photo interpretation procedures are difficult to standardize and need to be adapted to each image. There is, however, growing interest in computer-assisted photo interpretation.

2. Processing of digital data

Numerous photo interpretation operations can also be carried out by computer processing, which often facilitates the work.

• **Better visualization.** A look-up table enables visualization of data on a color screen. The user can modify the transformation to obtain the best contrast. A single or several bands can be visualized either in black and white or in color.

• **Printing flexibility.** The same flexibility exists for printing raw data or results on paper.

• **Mapping possibilities.** Once computer processing is made operational, it is much quicker and easier than photo interpretation. Three major techniques can be used for computer processing:

– **Geometric correction** makes the recorded image identical to conventional maps. The procedure is much easier with computer techniques than with photographic techniques. This type of processing is also necessary for multidate analysis and image mosaicking.
– **Multidate analysis**, designed to compare two images taken on different dates, requires that both images have the same geometry, which explains the need for geometric correction on one (or both) of the images so that they can be overlaid or compared with a map. When a study site is split between two images, they are then fused together, another reason for the importance of geometric correction techniques.
– **Classifications** consist in grouping image pixels in a certain number of classes and visualizing the result after having given each class its own color.

• **Surface estimates.** Once a classification has been defined, the number of pixels in each class is counted. This number is multiplied by the basic pixel size (0.04 ha for SPOT) to obtain the surface area covered by each class in the image.

• **Dimension reduction.** Landsat TM provides six radiometric values per pixel — the thermal band is not considered — which makes subsequent analyses particularly long and difficult as only three bands can be visualized simultaneously (one each for the three primary colors: red, green, blue). Computer processing using data analysis techniques enables all the information to be compressed into fewer (two or three) bands.

IV. – Digital preprocessing

A distinction is normally made between preliminary processing to obtain optimum presentation of the data and interpretation and evaluation of the data and results.

1. Preprocessing

• **Radiometric correction.** Radiometric corrections enable the reduction of distortions caused by the sensors and atmospheric conditions. For multitemporal studies, radiometric values obtained on different dates (different solar conditions) are standardized for proper comparison of the images. Reference features are selected for radiometric correction; they are objects on the ground whose radiometry does not change or whose variations are known. In data production, such preprocessing is generally done before final use.

• **Geometric correction.** Geometric correction is designed to rectify systematic image distortions caused by the sensing process (earth ellipsoid, satellite movements, flight path variations, sensing technology) so that the images can be overlaid on a map. Such corrections are made either on the basis of the orbit and altitude parameters recorded during the overpass or on the basis of distortion laws, to ensure that the image conforms to an accepted cartographic projection (e.g. UTM or extended Lambert II). The distortion laws are calculated on the basis of ground control points, whose coordinates are known both on the ground and image (road and railroad intersections, etc.). In some cases, it is not necessary to start with geometric correction as it may be more economical to undertake this expensive procedure only for the final image which is made up of only one band.

2. Methods for improving image contrast and data compression

In general, these methods improve data presentation before actual processing.

• **Contrast stretching.** For a single band visualized in a gray scale the data are normally coded from 0 to 255 (0 for the absence of light and 255 for maximum light). The simplest method involves vizualization of the 0 – value pixels in black, 255 – value pixels in white, and those of intermediate value in corresponding intermediate gray levels.

In reality, however, the entire range of tones is rarely used. In certain cases, the range actually recorded in an image can be very narrow with values between 40 and 80, which results in a poor image with few details.

With a computer the data can be reprocessed to transform the original 40 value into 0 on the new image (replacing dark gray by black) and the original 80 value into 255 (replacing light gray by white). The intermediate values between 40 and 80 are redistributed linearly between 0 and 255. The new image thus has more contrast and detail. This is called contrast stretching.

Furthermore, information located in a specific value range is thus given special treatment. There are more complicated methods than simple linear stretching to achieve such results.

• **Histogram equalization.** This technique aims to improve image contrast and data compression for an optimum analysis of the image. For example, the number of gray tones can be reduced from 255 to 5 and redistributed so that each tone has about the same number of representatives in the image. The number of different levels is therefore increased for areas with information.

• **Principal component analysis (PCA).** This technique aims to summarize information in the original bands (e.g. the 6 Landsat TM bands) into a smaller number of new bands (2 or 3). It defines the new bands and arranges them so that the first one contains the most information. Given the existence of correlations between the different bands of an image, the selection of the first three bands results in only a minor loss of information.

V. – Processing

Information can be extracted in several ways, but the most common methods are:

• **Statistical approach.** It is exclusively based on the radiometric value of the pixel and involves numerous density slicing and classification methods.

• **Other analyses.** These analyses are not confined to pixel-by-pixel classification; they also consider information contained in neighboring pixels or in the rest of the image.

1. Statistical processing

A pixel is attributed as many radiometric values as there are satellite bands. A pixel of a SPOT XS image (3 bands) can thus be represented in three dimensions (**Figure 5**). Each pixel has a representative point in this radiometric space. An image is made up of a cloud of points that can be processed in various ways. The basic method is to isolate parts of the cloud (or classes) and identify the corresponding pixels on the image.

• Density slicing

Based on the histogram of a single band, this technique consists in retaining only those pixels whose radiometry is between two values. Although it is very simple, it can separate some characteristic themes which often show up on the histogram as "bumps." The most common example is the separation of pixels of water in the near infrared band of the XS3 SPOT image (**Figure 6**).

• Classifications

Classifications consist in dividing the cloud of points into cubes, spheres or ellipsoids, each of which groups image elements from the same class to produce an optimum division.

When the cubes or spheres overlap, the assignment of a pixel to a particular class is determined by calculation. The simplest calculation is the comparison of distances between the representative point considered and the centers of the two overlapping cubes or spheres.

Classification methods can be divided into two main groups: supervised and nonsupervised methods. **Nonsupervised methods** were developed for situations where no field information is available on the zone. They consist in regrouping similar radiometric pixels into a fixed number of classes. The analyst can then give a name to each of the classes, which is not always easy. This explains why, in general, **supervised methods** are preferred when reference samples of the different classes to be identified can be located on the image. Supervised classification includes the following steps:

- definition of the legend and establishment of a map with samples for each class of the legend;
- location of the samples on the digital image;
- extraction of statistical parameters related to the samples and classes;
- verification of classification accuracy (confusion matrix using a second series of samples) and modification of the legend;
- classification of the entire image;
- printing of the map.

• Use of nonlinear operators and indices

These processing methods, which can also be considered as data compression methods, are derived from the analysis of physical phenomena. The resulting images have a concrete significance. The examination of the responses obtained in the red and near infrared bands leads to the definition of two indices:

— The **vegetation index** is linked to the activity of the vegetation cover. Leaf pigment strongly absorbs radiation in the red (R) wavelength, while lacunose parenchyma reflects a large part of near-infrared (NIR) radiation. Thus, during the vegetation development growth phase, biomass and pigment development result in an increase in near infrared and a decrease in red radiation. The contrary occurs at the end of the growing cycle. Several indices, proportional to chlorophyll activity, have thus been developed. One of the most common is the normalized difference vegetation index (NDVI):

$$NDVI = (NIR-R)/(NIR+R)$$

where the values vary between -1 and $+1$.

— The **brilliance index (BI)** reflects changes in the color of exposed soil and rocks: the change from dark to light tones is accompanied by a simultaneous increase in radiometric values in both bands. This axis, commonly called "soil axis," can be represented physically by the brilliance index:

$$BI = NIR^2 + R^2$$

The index also varies in inverse proportion to soil moisture and roughness.

• **Thematic input**

Thematic information on the area is used in different ways:

– for crop inventories, radiometric monitoring of different crops with the help of a portable device enables the determination of the best image acquisition dates to enable optimum analysis
– in the classification phase, the statistical characteristics of different classes can be determined by the radiometry of training zones isolated on the image and located in the field. "Supervision" of the process can be extended with the modification of the initial classes (changing the statistical parameters, eliminating or combining classes) or the creation of new classes in order to develop a representative thematic map
– for the final result validity is evaluated by using control zones which were not previously used for defining the classes
– preliminary breakdown of the image into homogeneous geographic zones to develop an accurate classification

2. Other analyses

Other types of analyses are required to study the relationship of a pixel to its context:

• With the appearance of high-resolution satellites (SPOT, Landsat TM), texture plays an increasing role in image analysis. Texture corresponds to a specific local aspect such as the patchwork pattern of tone of a forest canopy. Certain texture criteria area sometimes used in the classification process.

• Mathematical operators, called "filters," are used to eliminate specific noise from an image, to increase or decrease local contrast, to highlight or remove a specific theme from a classified image, and to automatically segment an image into homogeneous zones.

• Other algorithms are used to identify characteristic forms in the image (e.g. linear networks such as highways or watercourses). They are related to mathematical morphology.

The use of these techniques for remote sensing is still recent and further research is required.

3. Current trends

In addition to attempts to adapt mathematical morphology research results, efforts are made to link satellite data with other digital data. This should result in the integration of satellite image data into **geographic information systems** (GIS).

Such integration offers several advantages. For example, satellite imagery can be automatically segmented if the desired limits (administration zones, agroclimatic regions, etc.) are already stored in the GIS database. Supplementary decision-making criteria can also be introduced in the image classification process to improve the legend. For example, criteria such as altitude, exposure, and soil type can be introduced for a crop inventory.

VI. – Image processing systems

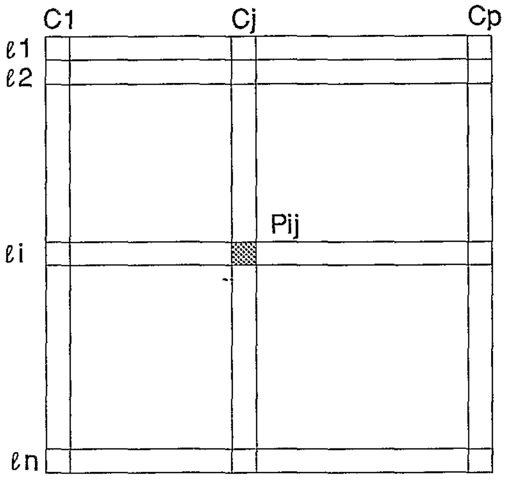
In the past, digital processing systems were only available on specialized — and thus expensive — equipment or mainframes. The recent microcomputer revolution has greatly enhanced calculation capacity and data storage and led to the marketing of image processing software (CARTO PC, CHIPS, DIDACTIM, ERDAS, MULTISCOPE, etc.) that can be used with standard IBM-compatible microcomputers.

The main consequence has been a sharp drop in the cost of a complete image processing system (microcomputer, peripherals, software), which now varies between Fr150 000 and Fr300 000 according to the selected configuration.

First used in research or training organizations, such equipment is now found in consulting companies and even with certain end users. Software manufacturers are developing software packages for specific applications (land use maps, automatic identification of urban areas, etc.) in collaboration with users.

With the spread of image processing systems and user training, the future will no doubt see the development of new applications and increased integration of remote sensing as a decision-making tool.

Figure 1. Structure of a remotely sensed monospectral digitized image.



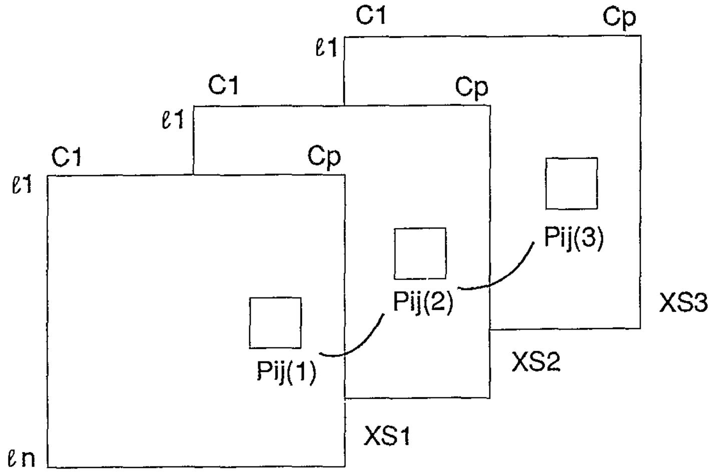
A pixel Pij is attributed three values :

1 - line coordinate L(i)

2 - column coordinate C(j)

3 - physical measure L(ij) determined by sensor and coded between 0 and 255.

Figure 2. Structure of a remotely sensed multispectral digitized image.



C: column

L: line

XSk: k band
k = 1,2,3 (for SPOT)

Figure 3. Histogram of digital values of a single band.

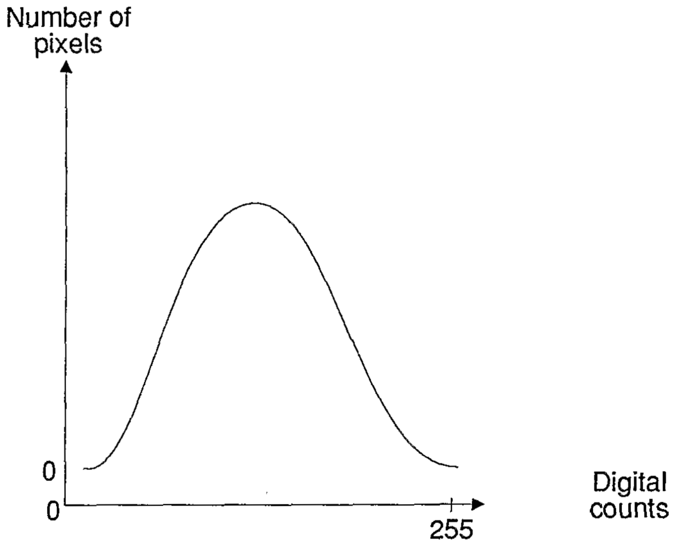


Figure 4. Spectral signatures of different features.

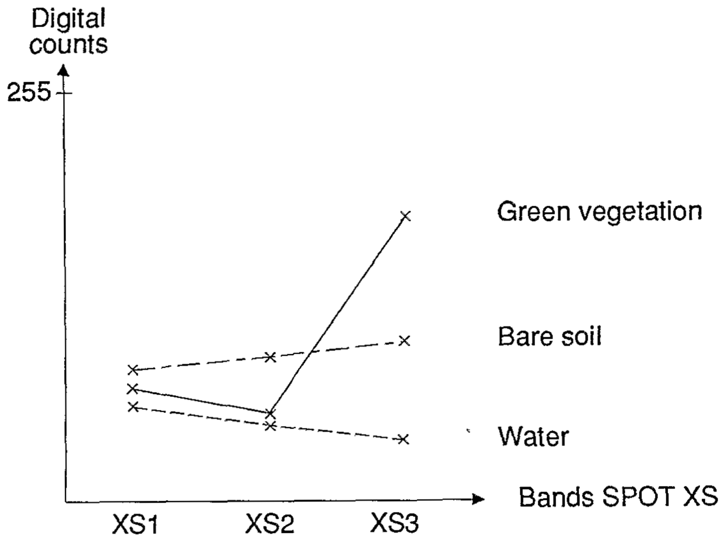


Figure 5. A pixel from a SPOT XS image in relation to the radiometric space.

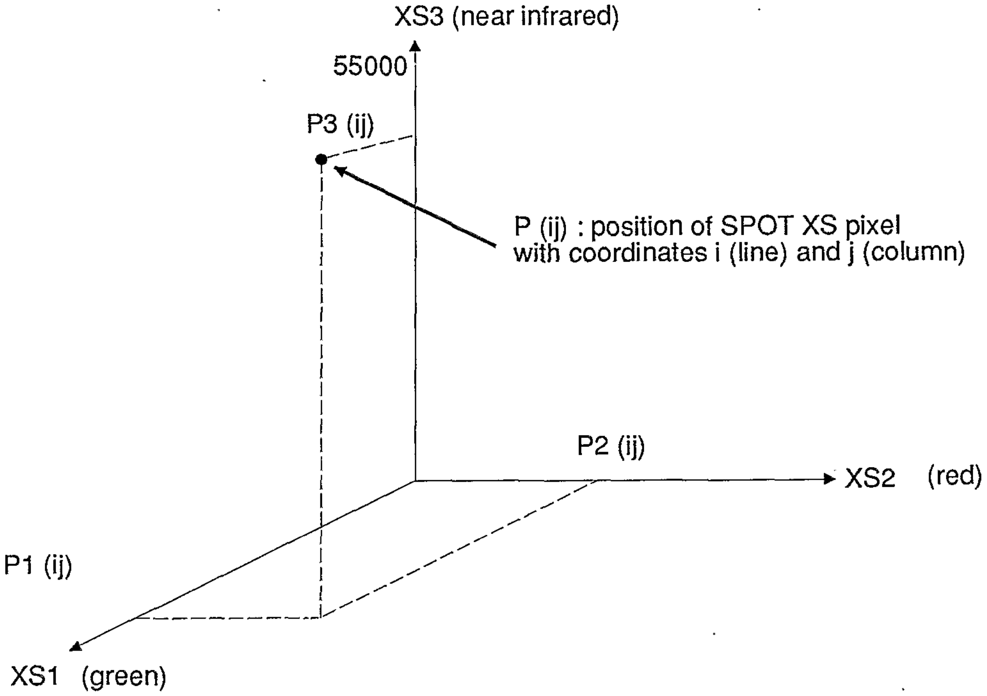


Figure 6. Caracterization of water by histogram slicing of the near infrared band (XS3).