

REMOTE SENSING

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16. Abstract  The article discusses efforts by various Mexican organizations to utilize the vast amounts of information being made available by satellites for use in map making and land use management. Software, hardware and other program requirements are outlined.			
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## REMOTE SENSING

by

ARMANDO JINICH

Remote detection permits a synoptic vision of large areas of our planet and opens interesting perspectives for the study of the resources of the surface of the earth.



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Remote sensing or teledetection has advanced considerably starting in 1972, the year when the first satellite of the LANDSAT series was put in orbit. Said satellite, specially dedicated to the study of terrestrial resources, receives information which is widely diffused and is made available to users in different countries. The possibility of attaining a synoptic image over large portions of the earth 185 km. on a side, with a periodicity of 18 days or less opens very interesting possibilities for the study of what happens regarding the resources of the surface of the earth.

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Some three years ago, because of the volume and form of the new data required, a work group engaged in the research, development and integration of computing, statistics, numerical analysis and electronics was organized at the Applied Mathematics and Systems Research Institute of the National Autonomous University of Mexico (Instituto de Investigación en Matemáticas Aplicadas y Sistemas de la Universidad Nacional Autónoma de México). Project PR [1] arose from the interest which some Mexican scientists had in mastering a technology which, they felt, would be useful to the nation. In the course of

these three years, computing systems and electronic equipment for image analysis were developed; personnel from various institutions was trained, and the viability and usefulness of the techniques were explored. This was carried out in collaboration with agencies such as the Secretaryship of Agriculture and Hydraulic Resources, the Directorate of National Territory Studies, the Federal Electricity Commission, as well as various research institutes of UNAM (National Autonomous University of Mexico). Support was given to projects such as the generation of soil usage maps, support of geothermal exploration, analysis of farming in irrigation districts, the study of the cultivable layers, the mapping of coastlines, and others. Information was provided to experts in agronomy, edaphology, geophysics, geology, cartography, etc., which they required in order to employ the new image analysis techniques and obtain the maximum information from the data. Some problems intrinsic to pattern recognition areas, geographic information systems and image classification algorithms were explored.

Remote sensing did not start with LANDSAT satellites, nor with the new image acquisition techniques. For some years, the methods which we now call traditional, consisting in the visual interpretation of aerial photographs, have been utilized with great success for various purposes [2]. Stereoscopic pairs of black-and-white and color photographs are used as a matter of course in the preparation of topographic maps. The photointerpreters are able to obtain a remarkable amount of information concerning the utilization, geology and edaphology of the areas being studied, as well as recommendations for adequate potential utilization. Infrared color photography has proved its effectiveness in the study of vegetable health and the early detection, and identification, of diseases in crops, fruit groves and vegetables. There exists an ample documentation [3] of this and the techniques have become a part of conventional methodology of cartographic agencies such as DETENAL, in Mexico [4]. This method has proven superior in terms of time and cost compared with the exhaustive terrestrial survey of study zones. For detailed study and to support photointerpretation, such studies remain indispensable in selected areas.

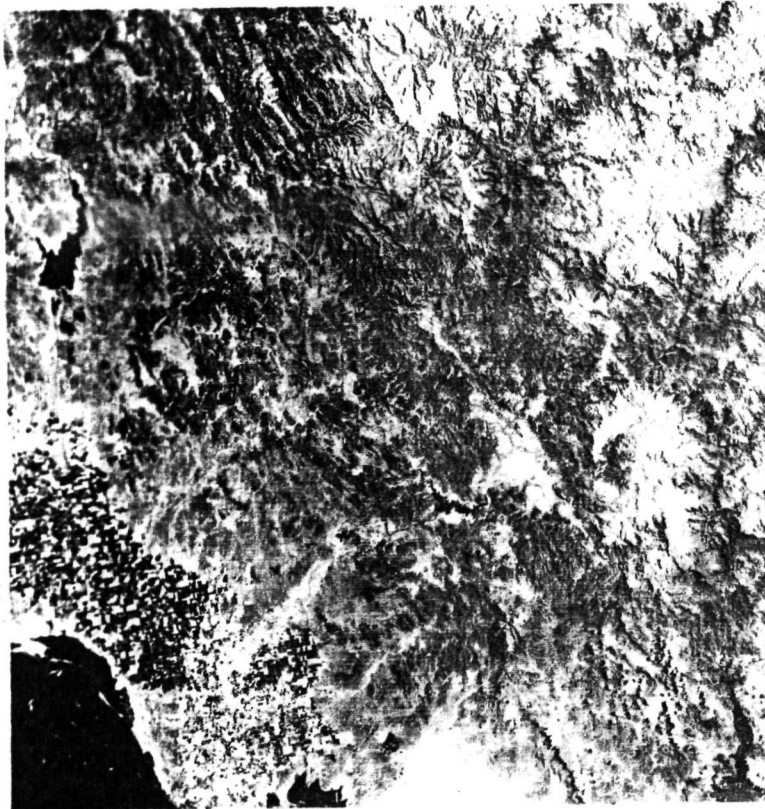


Figure 1. Irrigation district of Yaqui Valley. Full image of LANDSAT on band 7. An image such as this is processed to discover and quantify crops within an irrigated area. Methods permitting forecasting of total crops are presently being researched.

Software and hardware developments attained in the PR project are described below in order to explain methods described in the attached chart as well as some applications.

### Software

As regards software, the main task has been to develop the PR system, an interactive system presently functioning in UNAM's computer for which there will soon exist a minicomputer version.

The PR system allows for the handling of images from a terminal, going through a process which begins by reading a magnetic tape with the image of the area being studied, and ends by obtaining a

geometrically corrected thematic map. This system accepts information from satellites such as LANDSAT and SKYLAB, or sensors on board airplanes. The analyst, seated at the terminal, can carry out different operations on an image until the desired results are obtained. We shall list the operations typical of this process: a tape is acquired and the system is informed of its existence so that it may be catalogued; based on the tape, the analyst generates a subimage of the zone on which he is to work; the image is displayed using a method that makes it possible to stress contrast and utilizes the dynamic range of the output device. The analyst identifies on the image certain areas about which he has field information, and indicates their location and characteristics. He may carry out a non-supervised classification of small regions near the field data, with the purpose of determining them with greater accuracy. Afterwards, he studies the statistics--histograms, dispersion diagrams, means, variance--of the field data in order to verify the hypothesis that considers them as well-defined normal distributions, or in order to detect erroneous, bimodal or excessively dispersed field data. Once the data have been defined, it classifies it which are based on classes formed on the basis of the field data. Possibly, upon carrying out a first classification of selected areas, he may find it necessary to select a larger number of field data; after classifying the whole area, he may return to the field or to the aerial photographs for a second inspection and display of his data. Finally, he carries out the final classification. If he wishes to obtain a cartographic result, he carries out a geometrical correction, for which purpose he must select a series of control points--outstanding points of the image, the coordinates of which have been accurately located on a map. Such control points are the base used in order to carry out the transformation.

The above shows some of the functions that may be carried out through the PR system, as well as the use of a possible analysis methodology. Many others have been suggested, and some of them make a greater emphasis on supervised classification or on sampling techniques. [11].



Figure 2. Image of the reflective infrared band of a sector of Yaqui Valley, Sonora. It was made on the basis of the digital tape, using an electrostatic print. The exit scale may be arbitrary. A grid has been placed every 20 pixels in order to simplify the location of subareas. The image includes the city of Obregón, a part of the irrigation area, the road and the airport.

There are many other functions, such as the extraction of gradients to underline edges; to obtain the quotient of bands so as to emphasize, for instance, rocks with oxidation; to obtain images by average of neighboring pixels for lesser scale jobs; superimposition of images obtained on two different dates in order to take into consideration the variation not found in a single image.

It was possible to establish a very flexible modular system which has been changed due to interaction with the users. They have offered suggestions regarding some elements which could be added to the system, and different modes of operation. The system has evolved in this manner.

Other research fields, which are the natural consequence of the work carried out, are being explored. The first one is the development of a high-level computer language, specifically designed for the handling of images [12]. The structure of languages such as FORTRAN or ALGOL is not easily used for images. Because analysis techniques continue to develop, systems such as PR continue to be modified. An adequate language would simplify the programming and transportability of programs very much. The designed language permits the consideration of types of data such as an IMAGE and to carry out operations with them easily. The construction of a compiler for this language has been initiated. /35

The second task will include the development of an "automated photointerpreter assistant". It is a system that, besides an image and in manner compatible with it, provides information tailored to the area of study of the analyst. This would, for instance, allow the usage of the topography of the terrain for classification purposes for comparison with existing maps, etc. This system could be converted into an "intelligent" classifier, which, besides spectral information, uses elements such as texture, global relations, knowledge of the area, etc.



## Hardware

There are three basic aspects in the automatic analysis of images which require special equipment: the acquisition of the data, their processing and the distribution of the processed information in order to make it accessible to the human eye. Project PR is active in each field.

### Acquisition of images:

Until now, there has been talk regarding images acquired in digital form by means of multispectral scanners installed in an aeroplane or satellite. On occasion, it is necessary to digitalize the information of an image on the basis of photographs, or else to digitalize charts with topographic, geological, etc., information in order to use it together with images. There are several ways to do this. One of them consists in obtaining the information by means of a television camera, and converting the analog signal into digital values sampled at given intervals.

The interest which Project PR has in designing and constructing a digitalizer is the incorporation of information contained in existing maps. This process is presently carried out with digitalization tables, for which an operator must follow all the lines of the charts one by one. The process is slow and costly. The use of a TV camera, a digitalizer and appropriate algorithms to highlight the lines of the chart and to geometrically correct the distortion produced by the camera is a better method. This will be very useful to generate the geographic information banks which many institutions require and which are already being built [13].

### Distribution of images:

Due to the cost of the necessary equipment, the distribution of images represent a bottleneck for analysis systems. The gray maps resulting from the superimposition of characters in ordinary printers, or those, finer, which are obtained through the use of electrostatic printers, may be very useful for diverse applications are but far from accurate, especially in terms of color and output speed.



Figure 3. These illustrations show the capability which the PR system has in order to carry out geometrical corrections on images. To the original illustration at the left a sinoidal distortion was applied with the computer. This kind of process is utilized to eliminate from the images the distortion caused by the rotation of the earth, the movement of the satellite, etc., and to produce them in a cartographic manner compatible with a desired projection.

There are other costly solutions, such as equipment to produce color prints using photographic processes in which a laser ray, controlled by the computer, sensitizes a film. A solution which is increasingly more common and more economic, is that of showing the images on a color TV screen.

The TV screen image must be continuously reactivated so that it will not disappear. It is necessary to send the data to the screen after every refreshing cycle, generally every  $1/30$  of a second. In ancient times (in computer science, this means some five years ago) images were stored in discs in analog forms.

### Numerical images

Traditional photointerpretation techniques utilize methods of analysis that depend essentially on the production of photographic images, and underline some features of the information. The photo-

interpreter uses colors or gray, and the presence of features identifiable by a trained eye (alignment, drainage patterns, different textures, global characteristics, the presence of villages) in order to carry out the interpretation. The spatial and spectral variation present in the image is the source which gives rise to his analysis. The human eye and brain has an extraordinary capability to distinguish spatial information. The identification, for instance, of a linear feature which has merely been suggested in a complex mountain information is, for the eye, a simple task. To try to explain or imitate this process by any other means is a problem that has not been solved yet. In the spectral area, however, eye capability is more limited. To distinguish some 20 shades of gray presents difficulties, but with electrooptical methods it is simple to recognize hundreds of them.

The photographs which the first cosmonauts brought back showed the advantages of a wide-scale coverage. The morphologic features that went undetected became evident. A single image could be the basis for studies on the cultivable layer, the state of crops, the location of marine currents, cartography of islands and coastlines, over an extensive area. The Apollo missions obtained black-and-white images taken simultaneously with three different filters. These images represented the energy reflected by the terrain, in three regions or "bands" of the electromagnetic spectrum. Later studies showed that these "multispectral" images were very superior to normal images in colors that were obtained for the study of the geological structure, and to differentiate among several types of vegetation [15]. A fault in the photograph, the fact that the variations in reflectance are measured without gaging and in a manner quantitatively inaccurate, was corrected with the introduction of optical mechanical systems called "multispectral scanners", which were a part of the SKYLAB and ERTS-1 missions.

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The multispectral scanners look to Earth through an instantaneous vision field (IVF--CVI in Spanish) having an angle of several milliradians, and they cover an area of several square meters on the terrain, which depends on the height of the sensor. The incident energy in the sensor separates into different bands and its intensities

are measured. This energy is derived largely from the energy reflected and/or emitted by the area of the terrain observed. In the case of LANDSAT, it is an area of 79m. X 79m. (determined by altitude of the satellite, 918 km. and the IVF of the scanner 086 mr). A mirror that rotates continuously permits the scanner to successively scan different points on the terrain, along a scan line. The movement of the platform (satellite or aeroplane), on which the scanner is mounted, makes the successive scan lines advance over the terrain. In this manner, information on the whole area is obtained. The image resolution elements obtained are called "pixels".

Thus, multispectral scanners produce a series of values indicating the energy per IVF for each pixel in several bands of the spectrum. The values measured may be printed in a magnetic tape, and transported to Earth, or sent by radio to receiving stations. These values are normally digitalized in a block of 128 values, where 0 indicates the absence of energy and 127 indicates the saturation of the sensor. At the beginning and the end of each sweep line, the sensor registers the intensities of well-known sources, in order to obtain calibration values. Consequently, an image is a series of numbers. Once on Earth, these numbers may be used to generate (through a process inverse to acquisition) a black-and-white photograph for each one of the bands, or a color photograph combining three of the bands by means of filters. The photographs may then be interpreted using traditional methods. On the other hand, data may be treated, in an abstract manner, as an ensemble of measurements. From this point of view, the image is not the final result of data acquisition, but only an adequate way of visualizing them.

The automatic analysis of multispectral images is an ensemble of methods used to handle images, from a numerical point of view, in order to obtain results of interest.

The drastic reduction in the cost of memories permits storage in memory banks having random access. The amount of memory required in a high resolution system is great (512 x 512 points of 8 bits use 256,000 bytes) and the refreshing memory represents a high percentage

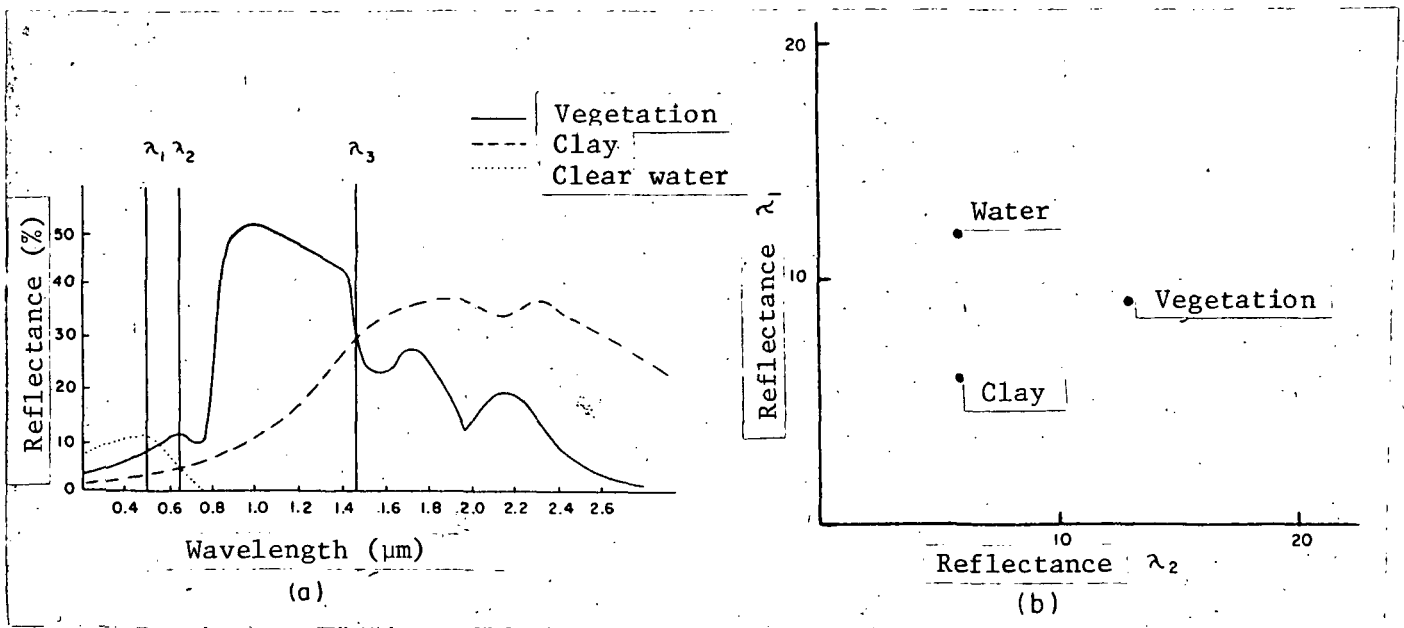


Figure 4. a) Reflection curves of three materials. They indicate a percentage of incident radiation which is reflected at each wavelength. b) Representation in one space of two dimensions of the reflective response in the wavelength. Note the value of the multi-spectral information: vegetation and clay are confused in  $\lambda_1$  and  $\lambda_2$ ; water and clay are confused in  $\lambda_2$  but not in  $\lambda_3$ . The usage of both allows to distinguish the three classes.

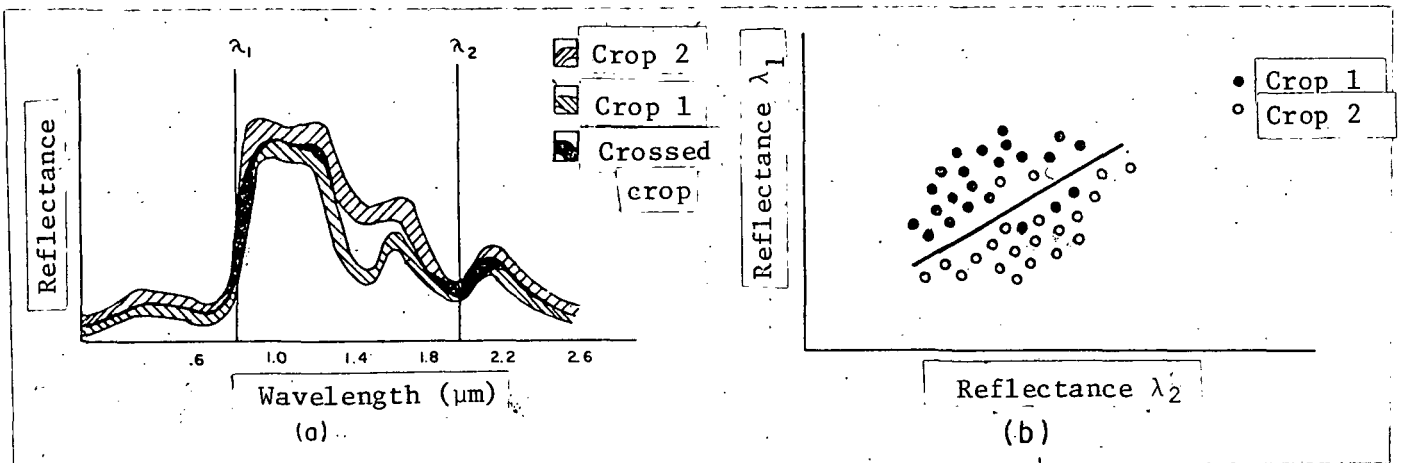


Figure 5. Despite the fact that crops 1 and 2 cannot be differentiated  $\lambda_1$  and  $\lambda_2$  are observed separately, it is possible to distinguish them by observing both wavelengths simultaneously. a) Crop reflectance curves. The wide lines represent the variability of reflectances within a class. b) Observations in the space of  $\lambda_1$  and  $\lambda_2$ . As it can be seen, it is possible to trace the dividing line between crops. The computer carries out this kind of separations in four or more dimensions.

of the total cost. Finally, a cost reduction is obtained as well as an unimaginable versatility through the use of other systems. In the PR project a color terminal that is in the last stages of construction was designed. The characteristics of this terminal were tailored mainly to multispectral images. The information to be deployed in the screen corresponds to 256 x 256 pixels of 32 bits each, and is stored in a rapid memory (150 nanoseconds) with direct access. The 32 bits are subdivided into four bands of seven bits each and four graphic bits which is superimposed on other information such as level curves, rivers, roads or, simply, letters and numbers in the pictorial information. An area of a LANDSAT image stored in this memory may be displayed on the screen using three of the four bands for red, green and blue canyons (an image in "pseudo-color"). Some peculiar characteristics of this system are that the computer to which it is connected may utilize the refreshing memory as if it were its own memory, as well as the image processing capability of the system.

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THE PR SYSTEM ALLOWS THE HANDLING OF IMAGES FROM A TERMINAL, GOING THROUGH THE PROCESS WHICH STARTS WITH THE READING OF A MAGNETIC TAPE WITH THE IMAGE OF THE STUDY AREA, AND ENDS BY OBTAINING A GEOMETRICALLY CORRECTED THEMATIC MAP.

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#### Image Processing

A LANDSAT image contains some 30 million bytes. Future satellites will have resolutions three and four times larger, increasing the data volume nine to 16 times (the SPOT satellite which France plans to put in orbit in 1982 will have a 20 m. resolution).

The method of classification with maximum complexity carries out 14 multiplications and 10 additions per pixel for each of the classes being treated [14]. This generates major computing problems which may be alleviated, to a certain extent, through software. Various very ingenious techniques were designed [15] in order to reduce computation time, but there is a limit which is not far from being attained. Another step is to solve the problem through

specialized hardware. Array processors are used successfully, but they are costly devices. The screen designed by PR offers another solution. As it was already mentioned, it is necessary to read all the pixels of the memory 30 times per second and send them to the color monitor in order to maintain the image on the screen. As they are read they may be passed through circuits specially designed in order to detect if their values are to be found within certain ranges in each band. If this is affirmative, a note to this effect is left in one of the graphic bits. These circuits, called comparers, are simple and fast. Based on them, the circuits of the PR screen can detect whether a pixel belongs to a certain hypercube in the space of intensities. The limits of the hypercube may be varied through software and, thus, all points of the screen may be classified in 1/30 second. At first sight, this classification seems rough, it is not difficult to see that more sophisticated ones may be approached as much as desired using this method.

It is worthy to mention a project of another group in the IIMAS, the results of which will be valuable for the PR project. It is a matter of the design and construction of a computer which has several microprocessors operating in parallel. The machine is called AHR [16], due to its heterarchic re-configurable architecture. This means that there is no control hierarchy to which the processors are subject; each one processes "whatever comes along", and the microprocessors are "experts" for these processes, but may exchange their function for another one which is more important in a given calculation. This machine will be applied to image analysis in which several class tests may be carried out at the same time and different pixels may be processed in a parallel.

### Applications

The PR system has been applied to several specific problems. One of the first applications was carried out in order to evaluate the system and was an analysis of the crops in the irrigation district of Yaqui Valley, Sonora. Air photography taken by DETENAL specially for this project was available on the same date when the satellite

shots were made in order to corroborate the results. The PR system was tested in that area and classifications with percentages above 80% were obtained. This work resulted in an honorable mention, the Banamex Award of Science and Technology 1976 for the group carrying out the PR project in the agriculture and cattle branch [17]. As of that date, the group has collaborated with various government agencies and university institutes, and it has an agreement with the Directorate of National Territory Studies (Dirección de Estudios del Territorio Nacional) for studying the possibility of producing cartography of the use of the soil on a 1:250,000 scale by means of automatic satellite image analysis. This agreement will permit DETENAL to update its cartography very easily in areas with intense change and at a lower cost than conventional methods would allow. Likewise, based on works performed and on the experience that IIMAS and DETENAL personnel have acquired, a complete map on a 1:250,000 scale (from the initial analysis to the final print) will be produced in the near future. The costs and time expended will be measured.

The group has also worked with the Hydraulic National Planning Commission (Comisión del Plan Nacional Hidraulico) in the analysis of the Pánuco River basin. The objective in this case was to evaluate the PR system in an area known to the Commission [18]. At present, the PR system is being transferred to a minicomputer where it will continue to be of use to said agency.

A project of great interest is being carried out with the Federal Electricity Commission (Comisión Federal de Electricidad) and the Electrical Research Institute (Instituto de Investigaciones Electricas), in order to explore the usefulness of remote sensing in geothermical exploration [19]. The analysis of images in the thermal infrared, from satellites and airborne scanners, is planned. The four areas having the most interest for the FEC (Sp.: CFE), from the geothermical point of view, are: Cerro Prieto, in Baja California Norte; Los Humeros, Puebla; La Primavera y San Marcos, in Jalisco; and Los Azufres and Cuitzeo in Michoacan. The images will be taken both by day and by night and will be superimposed and analyzed with



the help of terrain thermal behavior models.

Work is being carried out, employing the PR system on the terminals installed at UNAM, the Biology Institute (Instituto de Biología). Analysis of the Veracruz flora and the Center of Sea Sciences (Centro de Ciencias del Mar), on the analysis of the coastland of the state of Michoacan is in progress.

### Why use a Computer?

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A LANDSAT image covers an area of 185 km. on each side and is described by almost 30 million bytes (a byte may be thought of as a letter). A page of this journal contains some 6,000 characters on the average. More than 5,000 pages of "Science and Development" (Sp.: "Ciencia y Desarrollo") in one image; that one image is worth 1,000 words is clearly a conservative assertion. If this quantity of data is to be numerically processed it is necessary to utilize a computer.

What type of data analysis is carried out using a computer? We may indicate six major areas:

Processing, in order to improve the quality of the data, and guarantee better results in the latter stages of analysis, as, for instance, radiometric corrections to eliminate sensor instability, atmosphere effects, etc.

Classification, which is understood as the application of algorithms assigning all the pixels of an image to an interest category for analysis--a type of soil or crop, a type of rock or a forest variety, a degree of erosion, or salinity, etc.

Highlighting images in order to produce better results for visual analysis.

Geometrical corrections to eliminate spacial distortion and to



Figure 6a. Constitución de 1917 Press, band 7 (infrared), LANDSAT. The image has been geometrically corrected so as to eliminate the distortion produced by the rotation of the earth. b) Non-supervised classification of the same image. The four classes detected correspond to water, brush, range and crops.

be able to refer the points of the image to systems of geographical coordinates.

Simultaneous use of image information and data banks to obtain data about changes in time, or to support the interpretation task.

Extraction of characteristic features, texture of analysis, alignment detection, etc.

It would be too extensive to discuss all the processes mentioned above. Therefore, only a summary of the classification process shall be given.

Each pixel of an image corresponds to a point of space, the coordinates of which are the intensities in each one of the bands. It is common to suppose that a particular class of pixels (wheat, water, terrains in hydrothermal alteration) has, in that space a normal distribution with a given mean and variance. The classification problem consists in finding the partition in regions corresponding to each of the interest classes in such a manner that a pixel is classified in the class corresponding to the region to which it belongs. This partition must be such that it minimizes classification errors. This problem is very well known in statistics, and there exist procedures as that of maximum variance for solving it. The method requires that the mean vector and the covariance matrix of each type be known beforehand. The parameters are calculated on the basis of samples of the classes that the user provides the computer. These samples are called "field data" (the name "land truth" (SP.: verdad de tierra), used by some, is an abominable translation of the phrase that in the original itself is very inadequate). This refers to terrain areas which are known already, which have been located in the image and have been supplied in the computer. Due to the need to have this "training" stage prior to the classification, the method is known as "supervised classification". The literature regarding the subject has an ample documentation on its usage [6].

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Another group of methods has the name "non-supervised classification". These methods are based on algorithms which, without any knowledge of the terrain nor of the classes composing the image (except, perhaps, how many there are), purport to discover accumulations of pixels "close by" in the space of intensities. Each one of the resulting accumulations is to be interpreted as a class. These methods actually require mathematically the intuitive though rather imprecise notion of grouping by proximity [7,8] in any number of dimensions.

Figure 7



Figure 8a



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Figure 9a

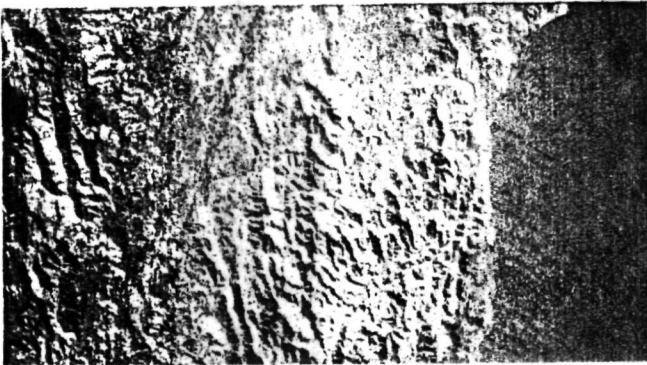


Figure 8b

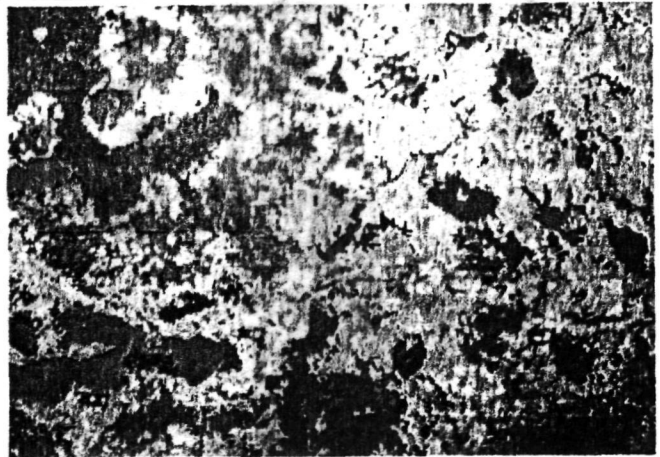


Figure 9b

Figure 8c

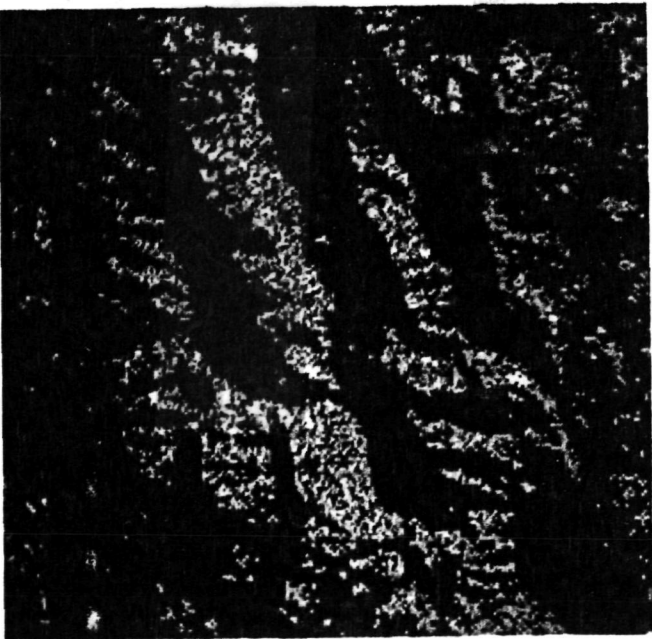


Figure 7. Classification obtained with a PR system in an area of the state of Querétaro. Note the problem of shadows in classification: The classes marked in blue and in green, to the center, are both evergreen oak woods, with a different exposure to the sun.

Figure 9a) Image of the S-192 multispectral scanner of SKYLAB; the band is thermal. The area corresponds to the geysers in California, USA, a geothermal area. b) Detail of the left center part of the same figure. The image has been obtained by highlighting the higher intensities. The pixel structure of the image can be clearly noticed. Some of the white pixels were associated with thermal features (NASA).

Illustrations a, b, and c in Figure 8 correspond to an area that includes part of the states of Guanajuato, Querétaro and Michoacán. The first two are automatic classifications of soil usage, obtained by using averages of 10 x 9 and 6 x 5 pixels respectively. The differentiated usage classes are: irrigation agriculture, storm agriculture, pine-woods, evergreen oak woods, bush, range, tulip wood, halophilous vegetation, water lily, water, floodable areas and urban areas. The third illustration (c) is a partial reproduction of the synoptic map of the same area published by the Secretaryship of Agriculture and Hydraulic Resources (Secretaría de Agricultura y Recursos Hídricos) with traditional techniques (it is shown as a reference). The classifications were obtained by experts in soil utilization of DETENAL, with support of PR project personnel.

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Both types of classifications have their specific scope, and several combinations and variations attempting to improve the result of the classifications have been developed [9,10].

The result of a classification may be used to generate a map or else to provide figures as, for instance, the number of hectares planted with certain crops in a given area.

The final technological form and the social value of remote sensing perception technology are in the process of being defined. This is the appropriate time for us to become qualified in this new technology, so that we can choose between the options available and avoid misusing resources which remain disconnected from the information and decision processes. It is important to be conscious of the fact that the solutions are not given and that the data from remote sensors, as any others, have no value if they are not translated into useful information that benefits individuals and organizations.

It is necessary to train personnel in this field that can evaluate whether, within their institutions, the use of remote sensing, especially using computers, will help them to function more effectively and at a lesser cost. In this matter, the users are the ones who should decide. Secondly, the personnel should establish the cheapest methods and use the equipment available. As for "total solutions" and "integral packages", it may be noted here that: 1. In this first stage of the technology there are no given solutions by pressing buttons. 2. The packages are only a collection of equipment and accessible programs, the total cost of which is out of proportion compared with partial costs. 3. The total solutions are an efficient manner of hindering both development and the capability to attain a technological independence.

Qualified personnel will integrate the new methods to the information system, decision-making processes or production of the said institutions.

The role that university researchers may play in this context is important. Their analysis, research and development capabilities must be put at the service of the study of technology. They must discover its advantages, demerits and limitations. It must be used to open "black boxes" and guide the users of technology and, if adequate, transfer it and develop it.

## Future Plans

Shortly, the PR project shall have a modular system for image analysis which will include electronic equipment and programs which can be installed in available computers (even in minicomputers). This system, or parts of it, may be transferred to the users. The software will continue to develop, especially for relating image analysis fields and geographical information systems. Support shall continue to be given, through joint projects and intensive courses, to those institutions wishing to try the methods.

The image processing area is very extensive, and it includes many fields, besides remote sensing. Some of them are: medicine, the analysis of cancerous cells and defective genes; the study of images derived from thermography, tomography, ultrasound and X-rays; in astronomy, the analysis of spectra; architectural design and animated cartoons; the study of structures and faults in components; the design of digital circuits. All of that requires experts in each area. The processing of images is only a powerful instrument to support their work.

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