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WORKSHOP ON REMOTE SENSING TECHNIQUES WITH APPLICATIONS TO AGRICULTURE, WATER AND WEATHER RESOURCES

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INTRODUCTION TO DIGITAL IMAGE PROCESSING FOR REMOTE SENSING APPLICATIONS

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THE PRINCIPAL PURPOSE OF WHICHEVER REMOTE SENSING ACTIVITY CONSISTS OF DERIVING USEFUL INFORMATION ON THE ENVIRNOMENT

REMOTE SENSING ACTIVITY INVOLVES A LARGE SPECTRUM OF KNOWLEDGE FROM MANY SCIENTIFIC FIELDS (MATHEMATICS, ATMOSPHERIC AND GROUND PHYSICS, INFORMATION TECHNOLOGY, ELECTRONIC AND OPTIC SCIENCES, ETC.)

THE RESULT IS GENERALLY GAINED THROUGH A SEQUENCE OF ANALYSIS AND PROCESSING STEPS WHICH IT IS NECESSARY TO DEFINE AND PLAN ACCURATELY BEFORE TO START

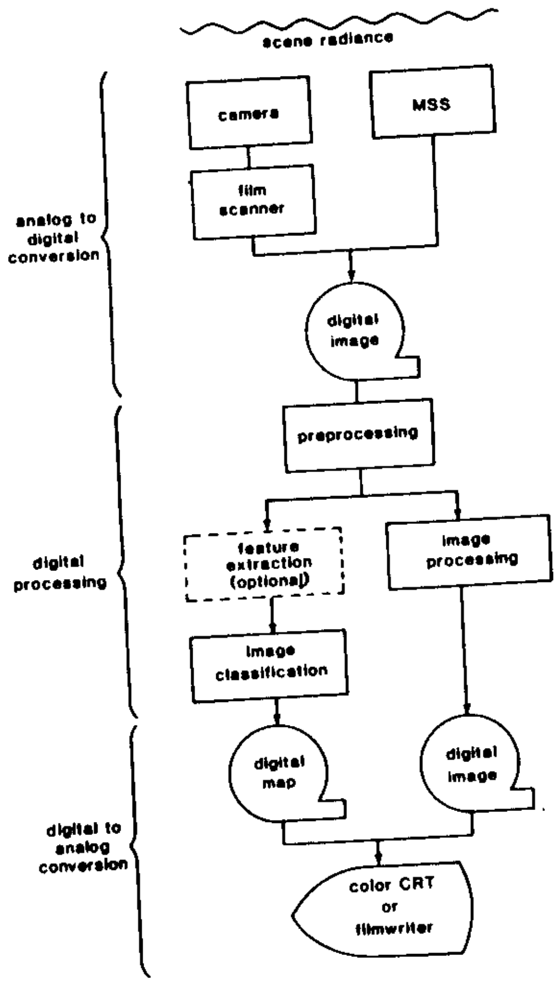

FIGURE 1-1. Data flow of digital remote sensing imagery.

DESIGN OF REMOTE SENSING DATA PROCESSING ACTIVITY

LEVEL 1. - TARGET DEFINITION

LEVEL 2. - SYSTEM DESIGN

LEVEL 3. - SYSTEM REALIZATION

LEVEL 4. - SYSTEM INPLEMENTATION

LEVEL 5. - SYSTEM VERIFICATION

LEVEL 1. - TARGET DEFINITION

The question is:

"WHAT SHOULD WE LIKE TO KNOW FROM PROCESSING OF REMOTE SENSING DATA ?"

or

"WHAT SHOULD BE DONE ?"

A satisfactory answer requires:

- knowledge of the problem in depth (meteorological, hydrological, ...)
- understanding of the specific application
- definition of the particular parameter(s) requested (temperature, soil moisture, biomass, energy budget, etc.)
- detailed list of the requirements (spatial resolution, radiometric accuracy, periodicity, ..)
- knowledge of the available means
- All auxiliary data available

LEVEL 2. - SYSTEM DESIGN

This level is concerned with the question:

"HOW SHOULD WE DO ?"

Once the objective has been decided, a sequence of actions is chosen, which may lead to an analytical or an heuristic solution, as well as an ad hoc one

This step generally may require:

- an understanding of the image formulation process
- the knowledge of the image degradation model

LEVEL 3. - SYSTEM REALIZATION

THE SOLUTION DECIDED BY LEVEL 2 MUST BE REALIZED AT THIS LEVEL

This level needs the examination of available algorithms and architectures which may be used for the realization of the designed system.

This level is concerned with issues as:

- speed
- modularity
- effects of finite precision arithmetics on the results (input and parameter quantization and

LEVEL 4. - SYSTEM IMPLEMENTATION

THE ALGORITHMS, ARCHITECTURES AND SYSTEMS DESIGNED AT LEVEL 3, NOW MUST BE IMPLEMENTED IN HARDWARE AND SOFTWARE

This level is concerned with LANGUAGES and TECHNOLOGY and it mainly includes evaluations on:

- cost
- speed
- flexibility
- transportability
- accuracy

LEVEL 5. - SYSTEM VERIFICATION

FINALLY, THE DEVELOPED SYSTEM NEEDS TO BE VERIFIED BY UTILIZING IT IN THE APPLICATIONS FOR WHICH HAS BEEN DESIGNED, AND ITS PERFORMANCES ARE EVALUATED

IT IS IMPORTANT TO NOTE THAT THESE FIVE LEVELS ARE INTERRELATED SINCE A DECISION MADE AT ANY ONE OF THEM AFFECTS THE OTHERS (so the task to go along these

Before defining the various categories of image processing algorithms, it is necessary to go in depth into some fundamental concepts of the images and their characteristcs.

The question that now arises is:

WHAT IS AN IMAGE ?

We can give many definitions, as:

"A REPRODUCTION OR IMITATION OF THE FORM OF AN OBJECT OR A NATURAL SCENE"

but no one enable us to process the iamge by computer; because these are QUALITATIVE and not QUANTITATIVE definitions.

Another question:

WHICH ARE THE IMAGE CHARACTERISTICS THAT ENABLE US TO CHOOSE THE MOST SUITABLE PROCESSING TECHNIQUES ?

and

HOW CAN WE EVALUATE THE QUALITY OF ONE IMAGE AND ..... WHAT IS THE "QUALITY OF AN IMAGE" ?

In order to process an image in a suitable way, descriptions as: "beatiful coloured image" are insufficient; it is necessary to start from another very different point of view

I M A G E - QUALITATIVE DEFINITION

"AN IMAGE IS NOTHING ELSE THAN AN INFORMATION STORED ON A PLANE"

Theoretically there is no differences between an image and a page of a book.

On the page there are many rows, each consisting of words. Moreover, each word is constituted of some characters chosen from an ALPHABET. The characters are put in a particular significative way, as to constitute significative words and meaning phrases.

In the same way, in an image (e.g. a photography) exists an "alphabet" that is constituted of the many gradations of the gray levels or colours, which represent the single "character".

Such "characters" are put on the image plane with and order which appears to be significative and so informative to the viewer.

As, if we compose the rows of a page choosing the characters in a random way we obtain an uninterpretable script, so, painting over a plane casually, certainly, we have the same result.

Unlike the page in which the characters of the alphabet are a DISCRETE set (a limited number of elements), the gray level values are a CONTINUOUS one, that is, they pass from one shade to the next in an impercetible way.

I M A G E - MATHEMATICAL DEFINITION

AN IMAGE IS A REAL VALUED FUNCTION:

$$g = f(x, y, l, t)$$

where:

x,y .... plane coordinates
l .... wavelenght or band
t .... time

THE VALUE OF THE FUNCTION AT POINT (X,Y) IS CALLED "BRIGHTNESS" OR "GRAY LEVEL"

IF x AND y ARE CONTINUOUS, THE IMAGE IS CALLED "ANALOG" OR CONTINUOUS

IF x AND y CAN ASSUME ONLY A LIMITED NUMBER OF VALUES BETWEEN A MINIMUM AND A MAXIMUM, THE IMAGE IS SAID "DISCRETE".

IF ALSO THE GRAY LEVEL CAN TAKE ONLY A FINITE SET OF VALUES, THE IMAGE WILL BE CALLED "DIGITAL"

In order to relate the mathematical function f(x,y) with the physical image, retaining the mathematical tractability, we usually reqquire that f(x,y) be:

- well-behaved analitically
- non negative
- bounded

That is, the function exists only over a finite plane:

$$0 < x < X$$

$$0 < y < Y$$

and can have a brightness value between 0 and a maximum

$$0 < g < Gmax$$

Moreover the image have to be defined for a particular wavelenght or range of wavelenght, and in a finite period of time, that is:

$$L_o < l < L_m$$

and

$$T_o < t < T_1$$

In other words, we suppose that the image can be defined only on limited period of time.

We will deal only with DIGITAL IMAGES and the principal digital techniques and algorithms commonly used to process remotely sensed images by computer.

DIGITAL IMAGE CHARACTERISTICS

Practically a DIGITAL IMAGE, whichever his source will be, IS A 2-DIMENSIONAL (2-D) ARRAY, MATRIX OR RASTER OF NxM ELEMENTS.

Each element of the image raster is called PICTURE ELEMENT or, more simply PIXEL

EACH PIXEL REPRESENTS THE AVERAGE OF ENERGY COLLECTED BY THE SENSOR FROM AN ELEMENTARY (FINITE) AREA OF THE SCENE, CORRESPONDING TO ITS INSTANTANEOUS FIELD OF VIEW (commonly called "BRIGHTNESS").

In other words, the pixel value is an ENERGY DENSITY from the area corresponding to each pixel.

RESOLUTION

THE SIZE OF THAT AREA AFFECTS THE REPRODUCTION OF DETAILS WITHIN THE SCENE AND IS CALLED "PIXEL RESOLUTION" OR "SPATIAL RESOLUTION" OF THE IMAGE.
As far as the area is reduced, more scene details are preserved in the digital representation

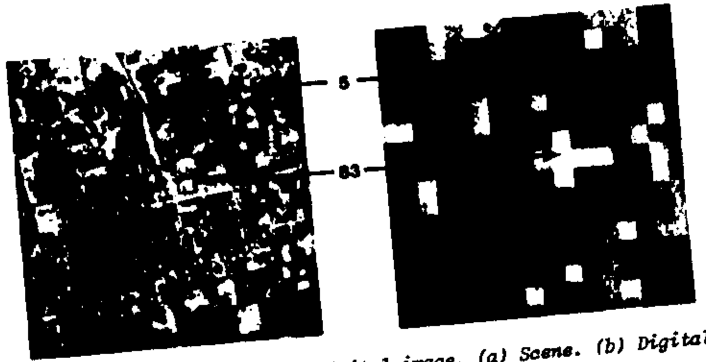

FIGURE 1-2. *Creation of a digital image. (a) Scene. (b) Digital image.*

NOTE: SPATIAL RESOLUTION AND SCALE

THERE IS NO CORRELATION BETWEEN "PIXEL RESOLUTION" AND "SCALE" OF THE IMAGE DISPLAY

The resolution is related to the sensor characteristics and determines the global amount of information (details) acquired and stored in digital form;

the SCALE is related only to the DISPLAY FORMAT and can be changed (e.g. enlarging the digital image by duplicatio of the pixels), without affecting in many cases the information content.
The pixel representation scale can be usefully used to control the final scale of the displayed image.

For high quality image display, the pixel size should be small (less than 0.1 mm), so that individually pixels cannot be distinguished at normal viewing distances.

For thematic information maps, however, it is desiderable to use larger display pixels, in order to have a very good visual evaluation fo the displayed information.

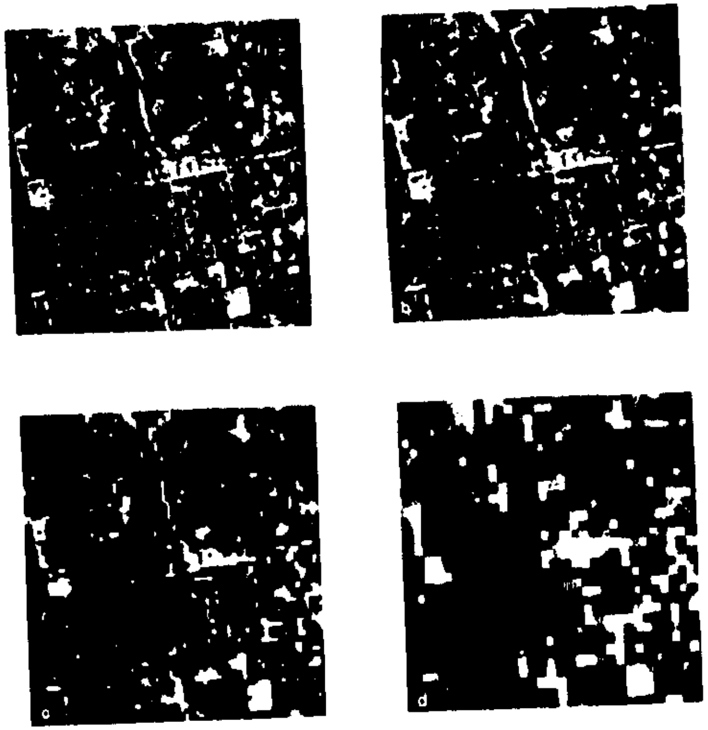

FIGURE 1-3. *Digital image structure as a function of pixel size. (a) 16 m. (b) 32 m. (c) 64 m. (d) 128 m.*

RADIOMETRIC RESOLUTION

Another fundamental parameter of an image is its RADIOMETRIC RESOLUTION, which depends directly by the sensor characteristics.

In a digital image the radiometric resolution parameter is represented by the number of different gray levels that appear in an image (e.g. 128, 256, 1024 etc.) Generally that number is a power of 2 and often the exponentiation is used, because it is representative of the NUMBER OF BITS nedeed to store that range (e.g. 6 bits, 8 bits, etc.).

More bits per pixel are desiderable for digital processing by computer, but for a visual analysis only a very limited number as 32, 64 or 128 are nedeed, because of the limited human eyes capability.

SPECTRAL INFORMATION

INTENSITY VALUES IN THE IMAGES ARE RELATED TO A PARTICULAR LIMITED RANGE OF ELECTROMAGNETIC WAVES OR "SPECTRAL BAND" IN WHICH LIES THE SENSOR SENSIBILITY.

So, all the pixel of one image are representative of the radiance of the scene under observation, in the same spectral band.

Table 2.1. Number of storage bits for various values of N and m.

N \ m	1	2	3	4	5	6	7	8
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152

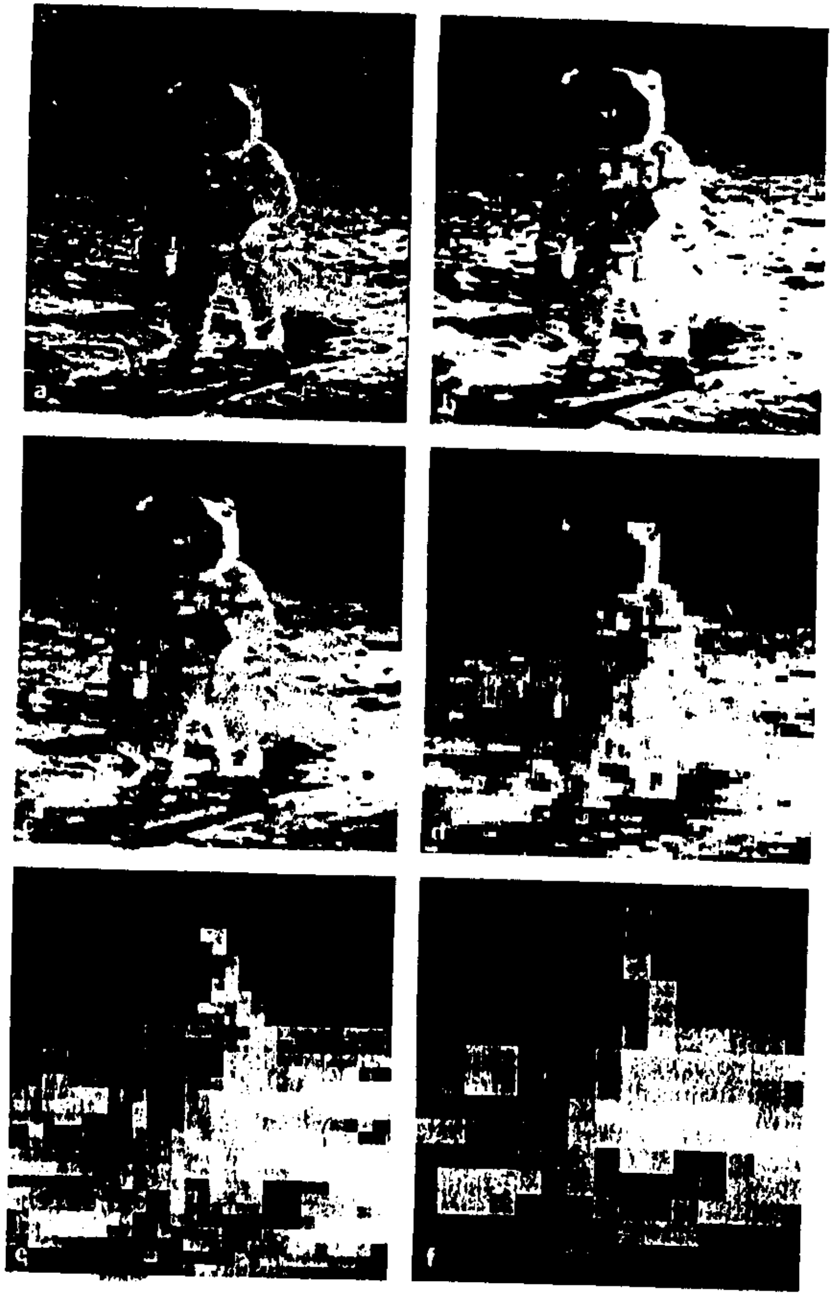

Figure 2.7. Effects of reducing sampling-grid size.

IMAGES PROCESSING TECHNIQUES

DIGITAL IMAGE PROCESSING INCLUDES ALL TH NUMERICAL TECHNIQUES USEFUL TO MANIPULATE DIGITAL IMAGES

We can distinguish three broad classes:

1. PREPROCESSING
2. ENHANCEMENT
3. THEMATIC INFORMATION EXTRACTION (CLASSIFICATION)

1. PREPROCESSING

It refers to the initial procesing of the raw data to calibrate the image radiometry, correct geometric distorsion and remove noise.

The type of required preprocessing techniques depends strongly on the sensor's characteristics, because GENERALLY THE PREPROCESSING IS DESIGNED TO REMOVE ANY UNDESIDERABLE IMAGE CHARACTERISTIC PRODUCED BY THE SENSOR

2. ENHANCEMENT

The principal purpose of enhancement techniques is to transform the original image in another image in which the required information is more evident and so more suitable for visual interpretation. The enhanced image could be easier to interpret than the original one.

3. THEMATIC INFORMATION EXTRACTION (CLASSIFICATION)

Image classification attempts to replace the visual interpretation step with an automatic quantitative decision. The results are generally obtained by using PATTERN RECOGNITION techniques. Among the thematic information extraction techniqus, the most important are the CLASSIFICATION ones, which try to to subdivide the image pixels in subsets, correspondingly to different classes of information on the ground.
The output from classification processing is generally a THEMATIC MAP, in which each pixel of the original image has been assigned into one of several classes of interest.
Naturally, image enhancement and thematic information extraction complement each other, and there are many interrelationship between them.

REMOTE SENSING PROCESSING

To gain the required result generally are necessary a lot of techniques:

1. GEOMETRIC CORRECTIONS AND CARTOGRAPHIC MAPPING
2. INTER-BAND REGISTRATION
3. NOISE AND DEGRADATIONS REMOVAL
4. ATMOSPHERIC CORRECTION
5. RADIOMETRIC CALIBRATION
6. INTERACTIVE ENHANCEMENT AND ANALYSIS
7. MULTISPECTRAL AND MULTI-IMAGES PROCESSING
8. PATTERN RECOGNITION AND THEMATIC INFORMATION EXTRACTION
9. ....