# 4 Image processing applications in archaeology: classification systems of archaeological sites in the landscape

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## 4.1 INTRODUCTION

In landscape ecology we may define as "patches" all non–linear surface areas differing in appearance from their surroundings, and as "matrix" a «surrounding area that has a different species structure or composition» (Forman & Gordon 1986). These concepts can also provide considerable help in understanding the specific features of digital sets, digital matrixes, and digital processing for landscape analysis.

In this context the archaeological landscape is very important in order to understand a survey and monitoring of a territory, and in order to discover the relationships between the ancient and the modern landscape.

The basic principle of image processing applications is that visible elements in the land surface change brightness level in the digital analysis. That is, in a homogeneous colour area, delimited and defined brightness alterations or chromatic discontinuities attest the presence of different objects. In general, extraneous elements on the land surface can be of natural or artificial origin. (Scollar 1977, 1978; Booth, Ipson & Haigh 1991).

We define an edge as the boundary between two regions with relatively distinct grey level properties. It is assumed that the regions in question are sufficiently homogeneous so that the transition between two regions can be determined on the basis of grey level discontinuities alone. If the regions are homogeneous we get a contour, and we can classify it in terms of a digital class/type. The procedure described in the following is meant to verify if the digital class corresponds to physical elements (in our case "landscape units" or "patches"). The edge–detection techniques are used for detecting points, lines, and edges in an image. Generally they are based on small spatial masks (O'Brien *et al.* 1982).

In digital analysis, it becomes very important to know the grey level or brightness level of known archaeological areas in order to compare them with archaeologically unexplored areas having the same features. We must remember that, within digital image processing, a discontinuity is the same as a mark on the surface that is, a region with different brightness or colour levels.

## 4.2 DIGITAL IMAGE REPRESENTATION

The reason for using colour in image processing is due to the fact that the human eye can discern thousands of colour shades and intensities. This is in sharp contrast with the eye's relatively poor performance with grey levels where only one to two dozen shades of grey in an image are detectable at any one point by the average observer.

The brightness of a region, as perceived by the eye, depends on factors other than simply the light radiating from that region. In terms of image processing applications, one of the most interesting phenomena related to brightness perception is that the response of the human visual system tends to "overshoot" around the boundary of regions of different intensity. The result of this overshoot is that areas of constant intensity appear as if they have varying brightness.

## 4.3 THE STORY OF AN ARCHAEOLOGICAL DISCOVERY BY COMPUTER ANALYSIS

Intrasite analysis using aerial photographs include:

*Figure 4.1: B/W aerial photograph of Ascoli Satriano (scale 1:33.000).*

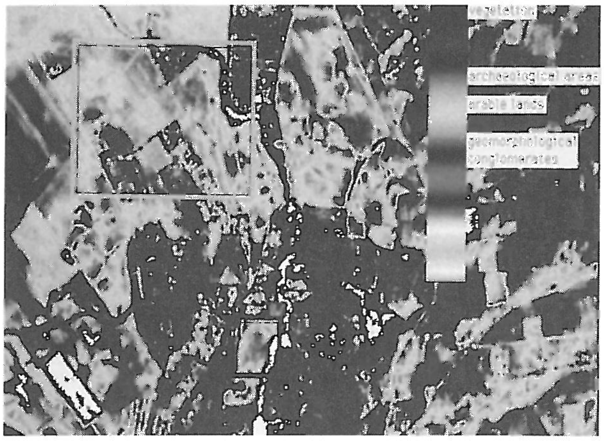


*Figure 4.2: Processed aerial photograph of the Ascoli Satriano territory (Foggia, Puglia). Inside the squares two archaeological sites have been discovered by digital analysis. The palette, here b/w, but originally processed in pseudo–colours, shows the digital automatic classification.*

1) the mapping of sites;
2) the identification of archaeological features through the interpretation of soil stains, plant marks, or marks of structural features;
3) the monitoring of site disturbance processes through time (Forte & Guidazzoli 1991).

In the following we will consider two fields of application:

1) image analysis that is related to image digital processing (e.g. aerial photo analysis);
2) image synthesis that includes rendering techniques: visual simulation of natural environments, texture mapping on Digital Terrain Model (DTM) or Digital Elevation Model (DEM) (Furini *et al.* 1991).

A major survey project was designed to create an archaeological map of Ascoli Satriano, Foggia (Puglia), in the South of Italy. The project was directed by the University of Bologna. This project focused on the analysis of digitised aerial B/W photographs, in the beginning, only in order to point out known archaeological sites and geomorphologic structures (Forte 1992a).

The original aerial B/W photo (taken in 1986) with a total extension of 22 sq. km includes part of Ascoli Satriano's landscape (Figure 4.1). The Carapelle river appears on the left and at the bottom appears the modern centre of Ascoli. If the basic principle of aerial–photo–interpretation is to identify and classify marks and anomalies on the ground, then in our case this type of analysis didn't give specific information. There are many marks in grey tones overlaying each other. They do not however suggest defined geometrical shapes that could be classified as an archaeological site. This may be ascribed to the presence of limestone conglomerate outcrops patterning the grey tones in the B/W aerial photograph. In all the area we were aware of only three Roman roads (in the centre of the image, Figure 4.1) and one Daunian settlement (the Iron age in Northern Puglia, IX–IV cent. BC.), called Villa Faragola (Figure 4.2, inside the larger square); this last site, discovered in the field, did not show special features visible in the aerial photograph. Beginning from such scant data, image processing was carried out mainly in order to analyse and classify the principal known landscape "objects" (structures): archaeological site, cultivated area, arable area, calcareous conglomerate area.

Before sampling, the image was photographed (Sony DXC–3000), digitised, and then recorded on a PC 386/20; in the end it was transferred to a Macintosh II. The software used (NCSA – to be discussed further below) is a public domain product developed at the National Centre for Supercomputing Applications at the University of Illinois, Urbana–Champaign.

The first step in processing was to select and magnify a part of the image area (Figure 4.2 and 4.3) for the following reasons:

1) on a bigger scale we get a better field of vision, and it is easier to identify anomalies and marks on arable fields;
2) the selected area is geomorphologically homogeneous;
3) the selected area includes one known archaeological site (Villa Faragola, Figure 4.3).

Using these data our aim was to develop a new methodological approach in image processing, in

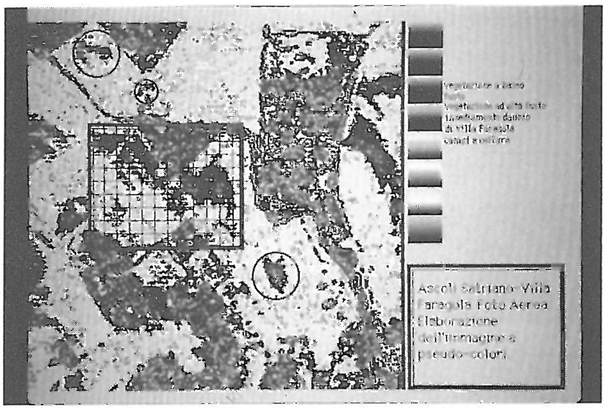


*Figure 4.3: The archaeological site of Villa Faragola, Ascoli Satriano (Daunian period: VIII–IV century BC). Pseudo colour processing (here in b/w) is used to enhance the brightness discontinuities and edges detected. Inside the square and the circles are the archaeological areas.*

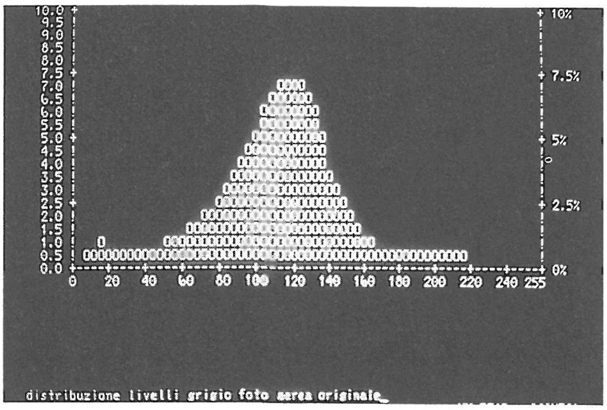


*Figure 4.4: Histogram digital equalisation.*

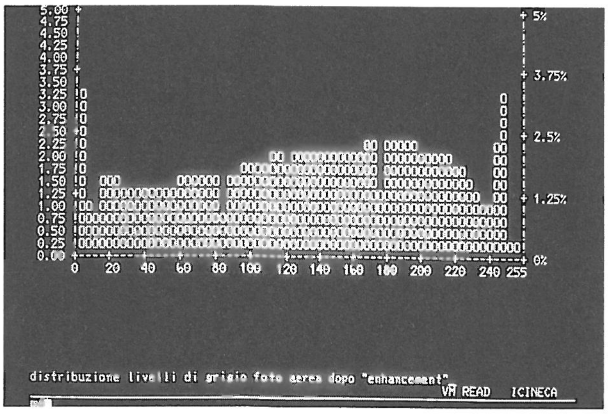


*Figure 4.5: Histogram digital equalisation.*

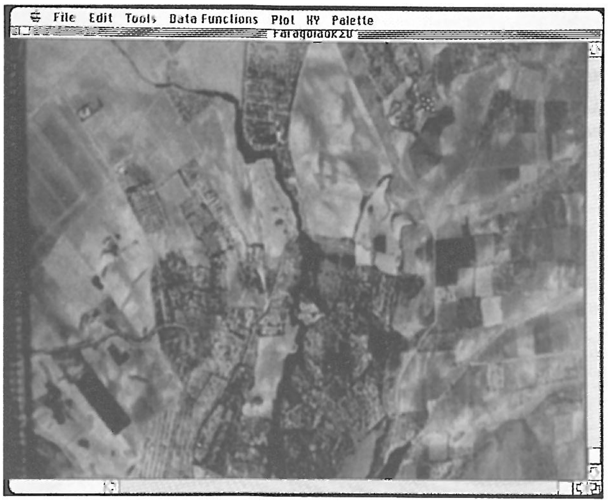


*Figure 4.6: Equalised arial photograph of the archaeological site of Villa Faragola (Ascoli Satriano).*

order to point out known archaeological sites, but especially to identify unknown sites.

With this goal in mind processing was carried out as follows:

- image (aerial photograph) acquisition, storage and digital conversion;
- grey level equalisation (Figures 4.4 — 4.6);
- contrast enhancement;
- a filtering experiment and edge detection to enhance marks and chromatic discontinuities;
- pseudo–color and look up table processing (Figures 4.2 and 4.3, here in b/w);
- image sampling on the known archaeological site (characterised on the surface by the presence of river stones, tiles, pottery, structures), with the analysis of refraction and brightness index of the surface materials on the soil (Figure 4.7: by digital cross–sections) in this context we must include other factors modifying the refraction index, for instance the soil dampness;
- using the previous sampling, perform automatic classification and identification of other unknown archaeological sites (Figures 4.2 and 4.7: inside the smaller square, the new site discovered);
- creation, at the end, of a predictive archaeological map, including all sites identifiable by digital analysis, but not yet investigated on the ground (Figure 4.8).

One of the most important techniques used — pseudo–colour processing (here all the images are necessarily b/w) — has allowed us to devise a look up table, obtained by plotting the 3 different RGB colour components one by one. I have used two different look up tables in the image processing: the first is developed in the blue component because the psycophysical properties of vision show

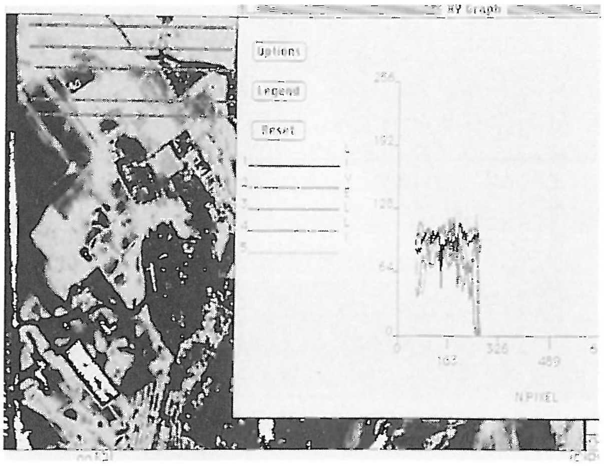


*Figure 4.7: Digital sampling of one archaeological site: grey level cross–section graph. The graph shows the brightness discontinuities of the archaeological marks on the surface.*

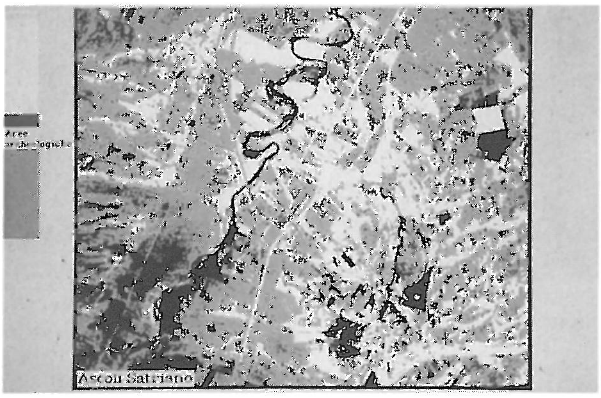


*Figure 4.8: Predictive archaeological map of Ascoli Satriano: the map has been realised by a synthetic digital look up table choosen according to the digital features of the brightness average values of the pixels classified as archaeological areas.*

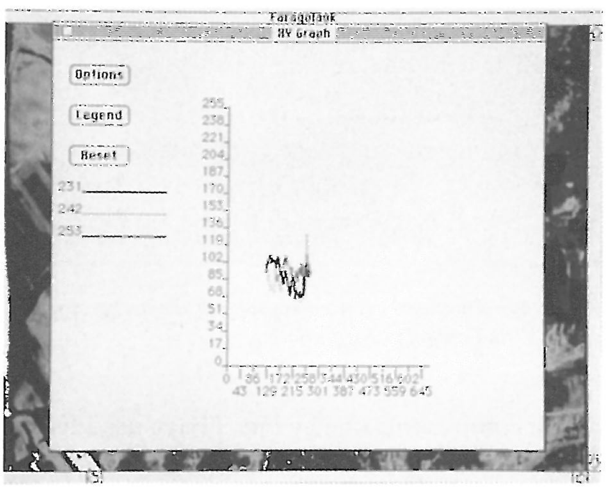


*Figure 4.9: Digital graph of two archaeological sites.*

high contrast sensibility in the blue zone; in this specific palette the components are modified using sine waves to vary frequency and amplitude within the palette in selected ranges, in order to enhance the discontinuities on the average value of the grey levels range (computed by statistical digital analysis) of the known archaeological area (Villa Faragola, Figure 4.2). The second look up table, which uses different chromatic tones, enhances the discontinuity between arable or cultivated lands and archaeological areas (Figure 4.3).

The images processed in this way give much more information than the original photographs; for example the calcareous conglomerates that in the original image showed the same grey tones to the human eye as other marks on the surface, in our palette show up dark pink (with different digital features), somewhat different from other terrain elements.

Since, in this processing context, the image is self–described in classifiable portions, it has been possible to sample digitally the known archaeological site of Villa Faragola, and use these data to identify other zones with the same digital features. By searching and comparing all the numerically homogeneous regions in the same image, we can select data points in specific areas and draw an XY graph through the pixels of the zones involved (Figure 4.7). The line is a selection of brightness values for those zones (Figures 4.7 and 4.9). This sampling allows us to check defined data sets and classify different types of morphological objects, like fields, rocks, cultivation's, or archaeological sites. Figure 4.9 shows the known sites digital graph at the top, and the new discovered sites graph at the bottom. They are practically the same, that is the digital characteristics concerning two Iron age sites (with analogous materials on the surface) are the same.

In this way the analysis draws attention to a defined homogeneous area 1.5 km. away from the known site (Figure 4.2 inside the smaller square). In fact the identical digital features relative to the Villa Faragola site classify it numerically as an archaeological area. The survey on the ground, completed in November 1990, confirmed the results of the digital analysis, discovering a hitherto unknown archaeological site, and showed the presence of iron age pottery, river stones, tiles, and clay elements.

Since the research results using the above mentioned methods proved to be very interesting, digital analysis was extended to the whole of the 22 sq. km. aerial photograph, in order to discover other unknown archaeological sites. This process, with an increased risk of error, can simulate the creation of a real predictive archaeological map, truly preliminary to the actual surveys (Figure 4.8). I have called this process *image/information processing inference*.

The predictive archaeological map of Ascoli Satriano was created with a synthetic look up table selected according to the digital features of the average brightness values of the pixels classified as archaeological areas. The final result depends on the precision of the grey level frequency (digital) statistical analysis computed on the basis of at least one known archaeological site. On the map (Figure 4.8) four colours/grey levels are used: black for remarkable geomorphologies, green for the cultivated lands, red for the presumed archaeological sites (here in b/w).

The survey on the ground of the predictive information suggested by digital analysis has proven to be exact in more than 68% of cases.

## 4.4 NCSA SOFTWARE

The image processing software NCSA, developed at the National Centre for Supercomputing Applications at the University of Illinois at Urbana–Champaign, has been used for all the applications shown here with the exception of the texture–mapping experiments. It requires a Macintosh equipped with 256–color capability, one megabyte of RAM, and System software version 5.0 or later. Better performance is obtained with System software version 6.02 or later. The number and size of images and datasets loaded at any time is limited by memory size. Two megabytes or more are recommended for best results. The modules it contains are: Datascope, Image, ImageIP, Paledit, Layout (Forte 1991, 1991a; Fabiani, Lanzarini & Rossi 1988).

### 4.4.1 The HDF file format

Hierarchical Data Format (HDF) is a multi–object file format for the transfer of graphical and floating– point data between machines. The design of this format allows self–definition of data content, and easy extendibility for future enhancements or compatibility with other standard formats. The NCSA software and the HDF structure file have been designed to facilitate the sharing of data between different researchers, projects, or different types of computers.

HDF files are self–describing; that is, it is possible to understand fully the structure and contents of a file just from the information stored in the file itself. They employ predefined tags to carry such information as the amount of data, its dimensions, and its location in the file. A program that has been written to interpret certain tag types can scan a file containing those tag types and process the corresponding data.

Related items of information about a particular type of data are grouped into sets, such as the raster image sets (RIS) and scientific data sets (SDS). Each set defines an application area supported by HDF.

In order to use HDF software, it needs access to one of the following computer systems: a Cray with UNICOS, an Alliant with CONCENTRIX, a Sun System 3 with UNIX, a Macintosh II, or an IBM PC, or compatible model, with MS–DOS.

### 4.4.2 NCSA Datascope

NCSA Datascope is an interactive data analysis tool. With NCSA DataScope it is possible to display 32–bit floating point scientific values in spreadsheet form and as simple scaled, interpolated, or polar colour images. Moreover, NCSA DataScope allows us to derive new datasets from scientific data by entering analytic equations in a special notebook window, and to record and save formulas, observations, and comments in a notebook. The data processing functions of NCSA DataScope allow us to:

- display 2D array data in a spreadsheet;
- scale and generate colour images from the data;
- find the data values that correspond to points on an image;
- enter and save comments and notations along with data;
- apply calculations from internal and external functions to data to generate derived datasets.

DataScope is particularly sophisticated in the pixel analysis, sampling and in the thresholding processing.

### 4.4.3 NCSA Image and Image IP

The original program was written for a Sun workstation. This version allows us to perform important data analyses and visualisation at a local desktop workstation. It is possible to visualise 8 bit raster images. both singly and with animation. If the file is of RIS 8 type, the image is immediately visualised. If the file is a HDF type, the data are interpolated before visualising the bitmap. The menu features allow us to :

- use colour, contour plots, 3D plots, shaded data plots, XY graphs, and ordered dither plots to display sets of data points;

- modify colour palettes;
- visualise bitmaps or 2D floating point matrices and display floating–point numbers.

Moreover it is a very interesting experience to visualise grey levels or colour contour plot distributions. It could be defined as "topographical representations" of the contour plot brightness levels, and it consists of creating digital level maps on the screen including all the regions of interest. This can be seen as a first step towards automatic classification, pattern recognition, or edge detection processing in order to enhance the discontinuities.

#### 4.4.4 NCSA PalEdit

NCSA PalEdit is a tool for the creation and customisation of colour palettes that may be used with other NCSA software such as NCSA Image. With PalEdit it is possible to modify the whole palette or individual entries in the palette, and to create a set of colours tailored to specific needs. Moreover it is possible to save palettes created or modified in NCSA PalEdit in either raw palette or HDF files. PalEdit supports four colour models — RGB (Red, Green, Blue), CMY, (Cyan, Magenta, Yellow), HSV (Hue, Saturation, Value), HSL (Hue, Saturation, Lightness). The RGB colour model describes a colour as a sum of the three primary colours. The CMY colour model describes a colour as a sum of the complements of the primary colours. These complements are called subtractive primary colours because they result from subtracting the corresponding primary colours from white light.

The HSV colour model was designed to be intuitively simple. It is based on the artist's concepts of tint, shade, and tone, here called hue, saturation, and value, respectively. Hue is the pure colour and ranges continuously from red to magenta, encompassing the colours yellow, green, cyan, and blue in a full cycle around the spectrum. Saturation refers to the purity of colour, and value is the brightness. With zero saturation, hue is irrelevant and value varies the colour between black and white. With zero value (black), hue and saturation are irrelevant. With maximum value, the saturation determines how much of the hue is used.

The HSL colour model, also called HLS, is very similar to the HSV model. The term hue has the same meaning in both models, and lightness is similar to value. In the HSL colour model, however, the maximally saturated hues are at half the maximum lightness; and with maximum lightness (white), hue and saturation are irrelevant. Saturation is slightly different in two models (Foley & Van Dam 1982).

#### 4.4.5 NCSA Layout

This module was developed to eliminate dependence upon highly technical inflexible programs for the production of visual presentations of two–dimensional data images.

NCSA Layout helps convey the results of investigations and analyses in a professional form. It allows display and annotation of 2D data images so that it is possible to photograph the Macintosh screen display with a 35mm camera and generate presentation–quality slides. Layout may include several images annotated with grid lines and tick marks, text, colour bars that display the range of the current palette and a coloured canvas. By loading user–defined colour palettes into NCSA Layout, it is possible to vary the appearance of the images and the colour of texts and canvas. It is also possible to save a layout as an HDF file, or as a raster image that may be transferred to other machines or programs for photographing, animation, or display.

### 4.5 IMAGE SYNTHESIS FOR THE SIMULATION OF NATURAL AMBIENTS: LANDSCAPE NAVIGATION

Certainly computer simulation of natural phenomena, is one of the most attractive and modern subjects for image synthesis. Simulation means all those processes, computed with mathematical models, the results of which can be visually represented on a graphic screen (Reilly 1988, 1989, 1990). Then, the model generated synthetic image can be compared with the available information, and the image becomes an instrument for furthering knowledge (Guidazzoli 1992).

This field includes the simulation of the landscape or natural ambients. There are many types of applications within the field; ranging from scientific research on simulators (Reilly & Shennan 1989) to ambient problems. Naturally, depending on the final goal, simulation will have different aspects: in a flight simulator you have to give the observer the full sensation and evocation of nature, leaving out the precision and accuracy of details. In scientific simulation, on the contrary, fidelity in reporting details should be very high. Here, the mathematical model, which is the basis of simulation, must be very sophisticated and reliable. Two problems exist in visual simulation of natural ambients or in 3D navigation. The first is the construction of a reliable Digital Terrain

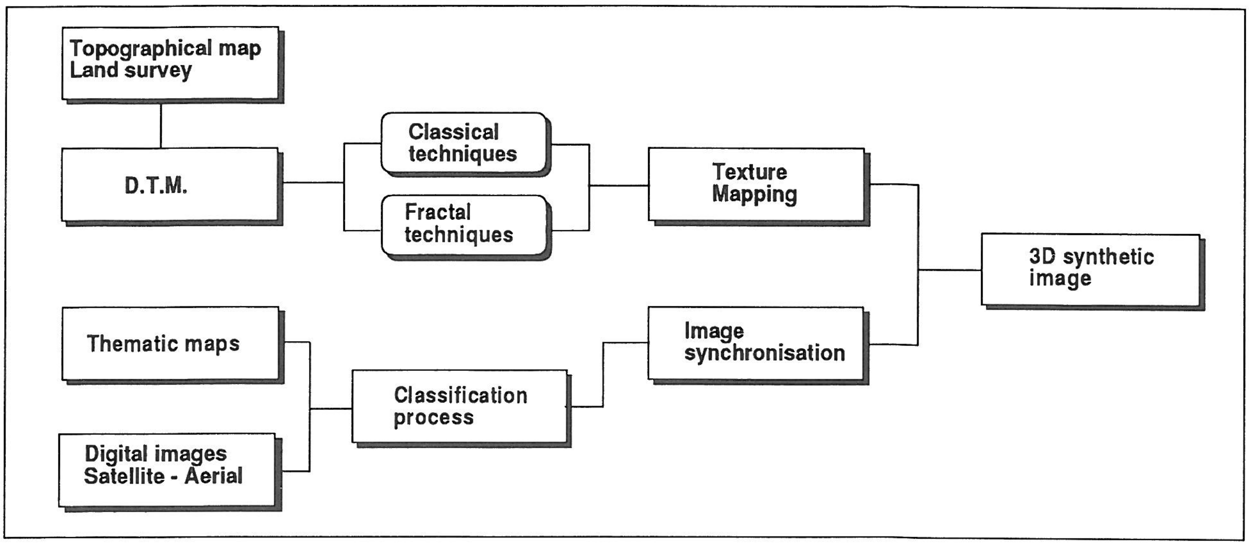


*Figure 4.10: Creation of a 3D synthetic image*

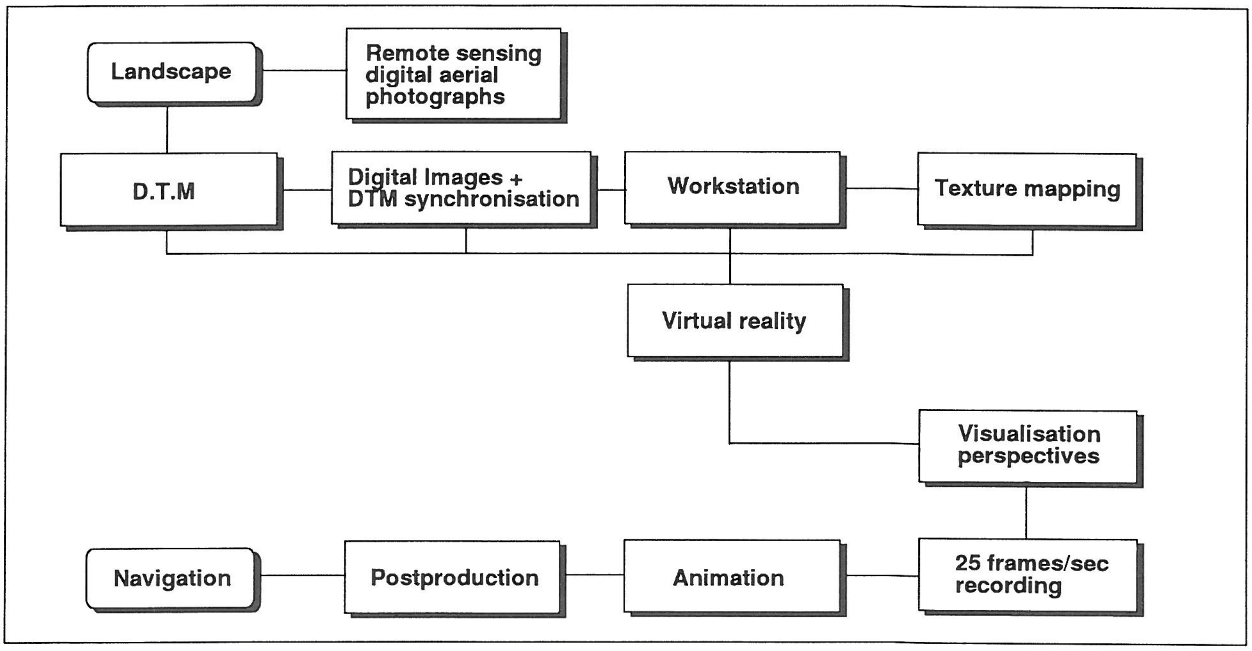


*Figure 4.11: Landscape navigation system*

Model, (DTM) (Harris 1987), the second one, closely tied to ambient simulation, is the terrain rendering, that is, the evocation of colour vision in the observer.

A DTM can be generated from isolines or from regular points, using classical models (linear interpolation and Kriging) or fractal models (Brownian interpolation).

In our case, the target is to make a landscape model (including archaeological sites) using DTM and satellite or aerial images; these applications include the following steps (Figure 4.10):

- acquisition of isolines from cartographic maps, in any resolution scale;
- DTM generation;
- digital image classification to determine the pixel distribution map for the DTM;
- image synchronisation (digital aerial photographs or satellite images synchronised with the DTM: in our case Figures 4.11–4.13),
- texture mapping and generation of 3D images (Figure 4.13).

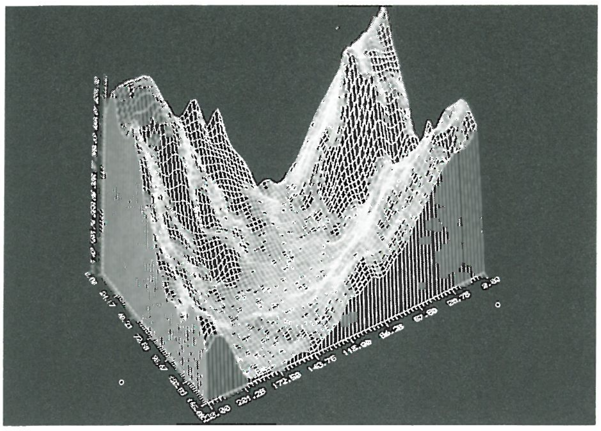

*Figure 4.12: D.T.M of Marzabotto and Reno Valley (Bologna).*

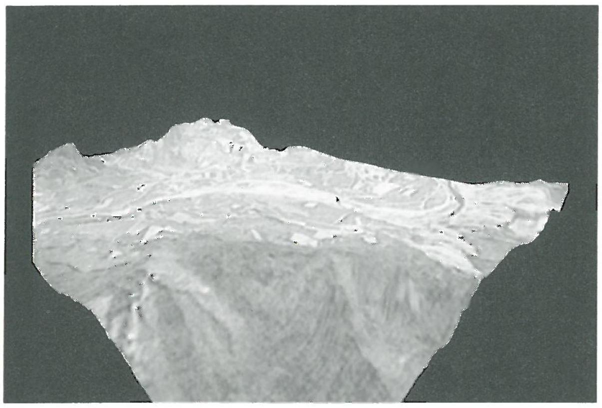

*Figure 4.13: Aerial photgraph texture mapping including the Reno Valley and the Etruscan town of Mazabotto, Bologna (marked with an arrow): an example of landscape navigation.*

In real life, surfaces are seldom perfectly smooth, with constant colour. More often, they are patterned or bumpy with colour variations. Texture mapping, bump mapping, and environmental shading make a computer–generated scene look more realistic by adding variations to the surfaces. Practically the texture mapping consists of the original image overlaid point by point on the DTM: the result is a realistic and significant landscape 3D image. This kind of simulation is especially useful to enhance the geomorphological characteristics of the landscape in connection with its evolution and the ancient settlements. Inside the image the researcher can move, navigate, explore, like in a realistic ambient.

Figure 4.13 shows the texture mapping of the Etruscan town of Marzabotto (in the picture it is indicated with an arrow) in the Reno Valley (Bologna). The very interesting result is a realistic and representative 3D image that includes important topographical and geomorphological information on the archaeological site and the Reno Valley, on the natural resources, and on the correlation between the Reno river and the Etruscan town. At this point we can simulate the exploitation of the landscape in a virtual space in which it is possible to process and study every single area.

It is created by overlaying a digitalized vertical aerial photograph (Figure 4.13) on the DTM (Figure 4.12) of this area. The DTM is generated from cartographic isolines and contour lines.

This kind of processing consists of different steps: the first one is the digitalisation of the aerial photograph (scale 1:30.000) in order to create a numeric input of a part of the Reno Valley including the archaeological area and a DTM model with a topographical sampling. The aerial photograph has been digitised with a CCD camera and converted into a numeric format in a raster file (RGB 24 bit planes, resolution 595 × 394 pels), and it has been aligned with the DTM model via a regular grid with a resolution similar to the one of the digital image.

For the final rendering special purpose hardware (a SGI workstation) has been used. For the polygon rendering we do not use the usual texture mapping techniques, but a geometric texturing has been produced (one polygon per pixel).

This technique allows lower sampling noise (anti–aliasing) without heavy software interpolation. In this way, the only problem is related to the dependence on the graphic library GL which is however implemented either on a Silicon Graphics or IBM RISC 6000 platform.

To produce the video animation the following steps have been implemented:

1) interactive tools are used to define positions (points) on the image displayed on a high resolution monitor;
2) points are selected pairwise analysing the model with respect to the tridimensional positions of the point of view and the observed point with the relative zenith and azimuth. The result is a set of keyframes stored in different files;
3) the intermediate frames are produced by a process of linear interpolation from the keyframes in order to simulate fluid movement (5600 frames).

The system produces one image in 3 seconds because of the high model resolution. This is a rate not suitable for real time animation.

To obtain a good animation the video has been recorded "frame by frame" with 25 frames per second.

In a few words, the essential data relative to the hardware and the software devices are the following:
*hardware*: workstation IRIS 4D/80 GT, VTR controller LYON Lamb Minivas, videorecorder BVU 950 Umatic SP;
*software*: device driver written in C to drive the video recorder;
*visualisation software*: C language, GL libraries animation;
*animation*: 224 seconds.
*Post-production*: Karma Video, Bologna

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