A NEW TOOL OF DIGITAL PHOTOGRAMMETRY: THE 3D NAVIGATOR

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ABSTRACT

Digital photogrammetry offers new opportunities and allows new applications, in particular to non-expert users. All the aerial and/or terrestrial images describing an "object" (i.e. a town, a monument building, etc.) and referred to in a common XYZ reference system, can be explored as a single large stereomodel. When the operator moves from one stereo-pair to an adjacent one, the system automatically swaps the images and the user has the illusion of moving in one virtual, continuous 3D space.
This new digital product simply consists of taking the images (using a digital camera or a scanner) and of carrying out the triangulation of the block, in order to obtain the orientation parameters of each photo. The result is stored on a CD ROM (or a DVD, in the case of very large blocks), and it could be named "stereo-photomap".
The digital instrument that is suitable for exploring a stereo-photomap has been set up by providing a simple stereovision device (a PC equipped with liquid crystal shutter glasses, etc.). The end user has access to all the information offered by the images, without the need of a preliminary restitution: he can select and measure what is of interest (X, Y and Z co-ordinates of points, distances, areas and so on) at that particular moment.
The present paper describes the "3D navigator", which has been implemented on a PC, where the user can move freely inside the stereo-photomap: the change of the images is automatic and transparent to the operator.

1 INTRODUCTION

Among the different techniques available for carrying out a metric survey, photogrammetry has always played a basic role, mainly due to its obvious advantages, such as the construction of a photographic archive and the possibility of measuring and drawing the required elements only when necessary.
Digital photogrammetry seems to offer more advantages. The required hardware for digital acquisition and restitution units are available on the widespread and inexpensive market of DTP scanners and PCs. Automation of the most phases of the photogrammetric process, such as interior and exterior orientations and collimation of homologous points, allows the end user to easily become a skilled photogrammetric operator.

2 THE STEREO-PHOTOMAP

In analytical photogrammetry, once the orientation parameters have been determined, the X, Y and Z co-ordinates of a point are quickly obtained, simply by collimating the homologous images of the point and measuring their fiducial coordinates.
In digital photogrammetry, the procedure is even simpler: measurements are implicit, due to the pixel position in the image matrix (nr. of the row and column) and the two homologous pixels of the point of interest can be automatically identified.
It is in fact well known that the homologous of a selected point can be carried out by means of a "matching algorithm": for the first time in the history of photogrammetry, the human stereoscopic view is not essential for an accurate identification of the homologous points!
The accuracy is similar that obtainable by an experienced operator, even though a low resolution of 800 dpi is used.
Therefore, an oriented stereo-pair can be considered as a complete metric survey of the represented object: the user himself can select, among all the image points, the points of interest, without the need of being an experienced photogrammetric operator.
The above described properties of a single stereo-pair can be extended to a strip or a block of photos.
The set of oriented stereo-pairs that represent an object could be called a "*stereo-photomap*". *STEREO* because it is observed in 3D; *PHOTO* because it appears as a photographic image; *MAP* because it contains all the metric information,

just a traditional map, in a single 3D reference system.
In other words, the stereo-photomap can be considered as the three-dimensional evolution of the traditional ortho-photomap: a correct 3D geometry is directly connected to an uninterpreted photo image. The use is similar: the final user observes and measures the points of interest, according to his particular requirements and applications.
The stereo-photomap can at the same time manage aerial and terrestrial images in a common reference system. This is an interesting and powerful investigation tool, when the object of the study is an urban area: the user can shift from aerial to terrestrial 3D views and *vice versa*, in an unique geo-referenced environment.

2.1 Production of a stereo-photomap

The production process of a stereo-photomap follows the standard procedures used in a traditional photogrammetric survey: image acquisition, survey of a control network and photogrammetric triangulation (which is the simplest way of determining the orientation parameters).
Digital images can be directly acquired using a digital camera or by an indirect process: a classical photographic camera and a photo-scanner. As already mentioned, the orientation parameters can be determined by means of photogrammetric triangulation. The bundle block adjustment procedure is recommended (ex: ORIENT by TUV), in particular when non metric cameras are used.
Specific software for digital automatic triangulation is already available on the market, both in workstations or PC platforms.
At the present state-of-the-art of digital techniques, the price of a stereo-photomap can be estimated as about the 30% of a traditional photogrammetric survey.

3 THE 3D NAVIGATOR

In a traditional map, the resulting drawings allow measurements of geometric elements, such as co-ordinates of single points, distances, areas and volumes. The required measuring instrument is a simple ruler.
In a more modern approach, results of the survey are recorded in digital form: in this case, a computer and an appropriate CAD software (e.g. AUTOCAD, MICROSTATION, etc.) are necessary for such enquiries. It becomes easy to automatically derive other graphic products such as horizontal and vertical profiles.
If a stereo-photomap is available, an *ad-hoc* instrument must be conceived and devoted to the correct and complete use of this new type of "map".
This new instrument, which has been called "3D NAVIGATOR", is described in the following paragraphs.

3.1 Properties of the 3D NAVIGATOR

Considering the peculiarity of a stereo-photomap, the 3D NAVIGATOR should offer the following performances:

- approximate stereoscopic collimation of homologous points by an operator (not necessarily an expert), the refinement being assured by the system;
- easy movement inside the whole photogrammetric block without problems when passing from one model to another;
- easy exchange from aerial to terrestrial 3D images and *vice versa*;
- quick and precise measurement and recording of point co-ordinates;
- calculation of distances, areas and volume after selection of the interesting points;
- basic procedures for the restitution of plots, profiles and DEM.

In order to obtain the maximum efficiency, the 3D NAVIGATOR uses many of the automatic procedures offered by digital photogrammetry.

3.2 Basic hardware configuration

The 3D NAVIGATOR has been designed with the aim of producing a low cost and a user-friendly instrument. It has therefore been developed on a PC platform.
All the images are supposed to be recorded at a 800-dpi geometric resolution (or better) to obtain a good visualisation of the details. A true colour image, aerial photo format (23 cm x 23 cm), requires about 150 Mb. The amount of data for each image becomes only 10 Mb, in the case where a 6 cm x 6 cm format is used . .Considering the 3D NAVIGATOR only uses the overlapped parts of the images of a stereopair, each model requires about 180 Mb or 12 Mb for a terrestrial model, if an overlap of 60÷70% is assumed.
The PC used to develop the 3D NAVIGATOR prototype has the following specifications:

- PENTIUM II processor – 400 MHz
- RAM 256 Mb

- 2 HD 9 Gb each
- 21" high resolution monitor
- active polarised screen with passive polarised glasses.

The RAM size allows the management of the overlapping portions of a stereo-pair, saving sufficient space for other purposes.
One of the two hard disks is reserved for storing the images while the other one is reserved for the software.
Even in the case where the 23 cm x 23 cm format is used, the hard disk can record up to 60 colour images or 180 b/w images. If one supposes the images are at 1:8000 scale, which is suitable for a 1:2000 survey, the area covered in 3D is about 83 Km^2 (color) or 240 Km^2 (b/w).

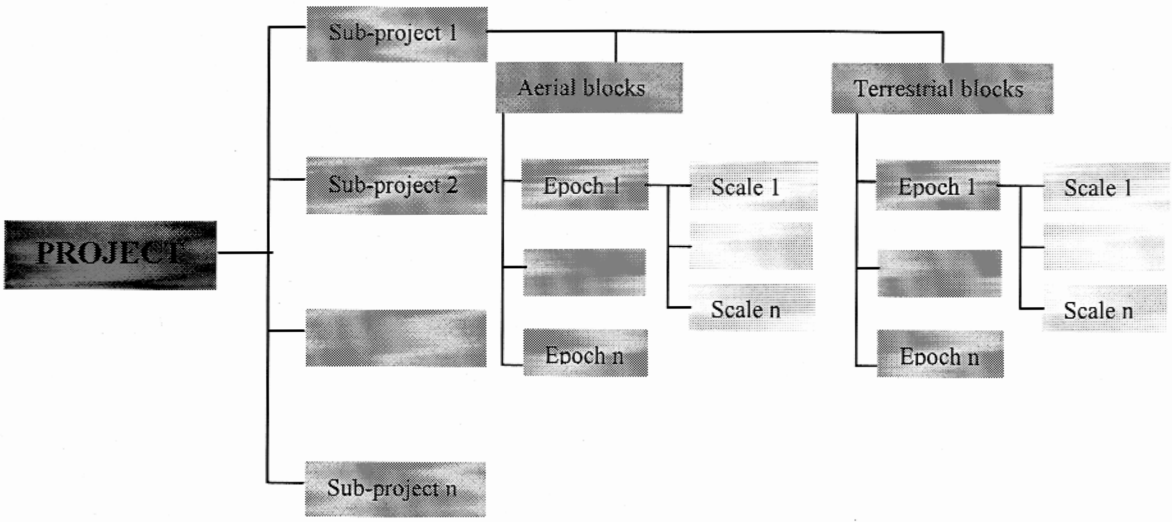

Figure 1. Data structure of the stereo-photomap

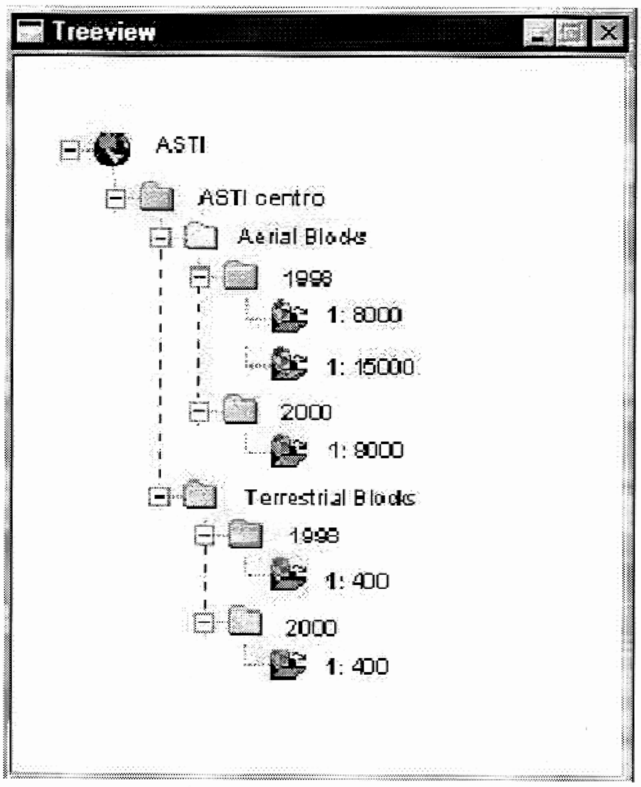

Figure 2. Data organisation in the 3D NAVIGATOR

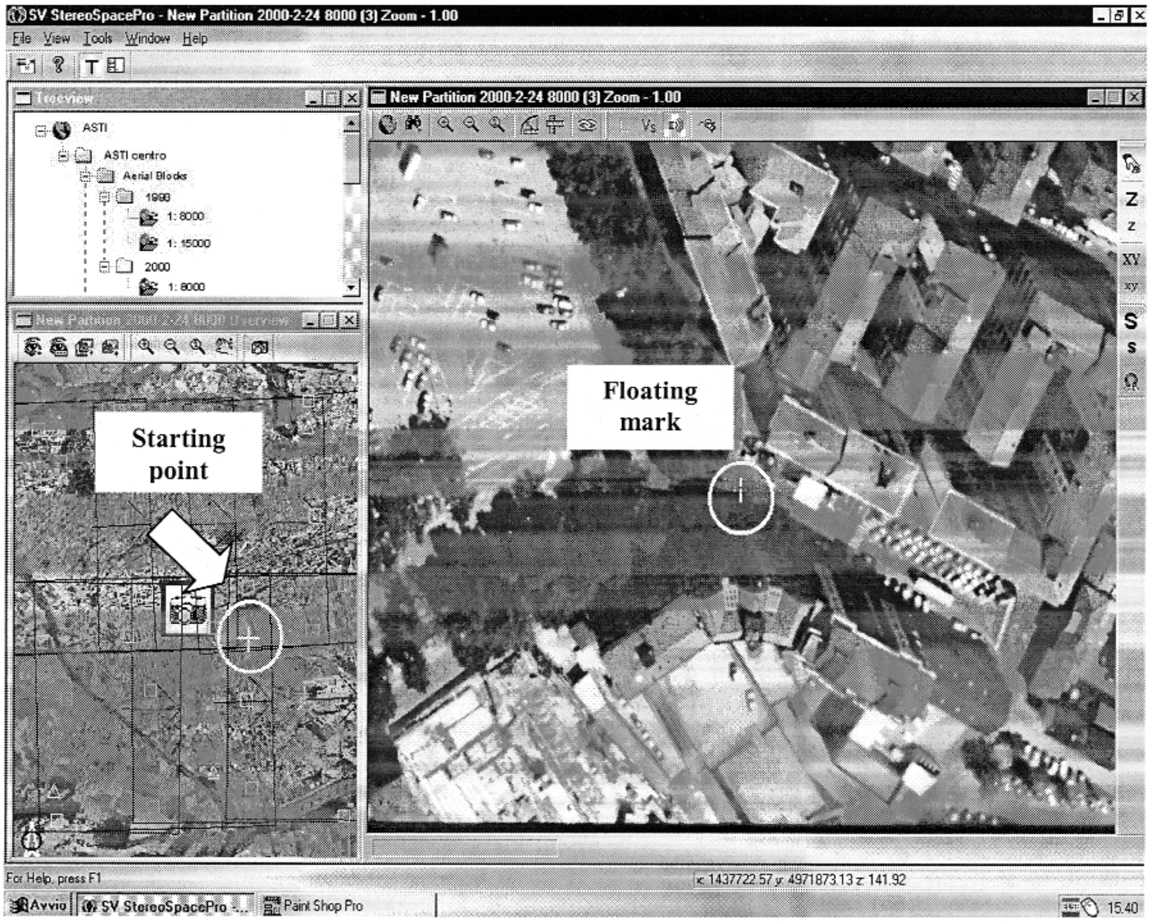

Figure 3. Starting the 3D NAVIGATOR

3.3 Data structure

All the data of a "project" (images and their calibration and orientation parameters) are organised in a hierarchical structure.

In detail, each set of images that describes an object (e.g. a region, a town, a single monument, ...) is recorded in a directory named PROJECT. Each project can be subdivided into subdirectories, named SUB-PROJECTS, containing the images of a part of the object (e.g. a significant part of a large town). Each sub-project can be represented in aerial and/or terrestrial blocks. Each of these two last directories can be subdivided again into further sub-directories named EPOCHS, in order to separate the images taken at different dates. Finally each epoch can be partitioned into subdirectories named SCALES where the images with the same scale factor are recorded. Figure 1 shows one of the possible structures of the stereo-photomap; the "builder" conceives the structure in order to satisfy the goals to be reached.

The proposed hierarchical structure allows the user to choose which part of the stereo-photomap he wants to explore, and optimises the way of archiving data related to the object of interest.

Figure 2 shows the structure of the stereo-photomap of the Italian town of ASTI. The aerial block (50 images at scale 1:8000) has been connected to some terrestrial stereo views of buildings, squares and roads (images at 1:400 scale, suitable for architectural surveys at scale 1:100).

3.4 Basic software configuration

The 3D NAVIGATOR software has been developed in WINDOWS98 environment, a world-wide known operating system. The screen can be divided into multiple independent windows, 2D or 3D: this allows one to display drawings, images and stereo-models of the object at the same time. A fixed floating mark in the middle of each 3D window allows stereoscopic collimations and measurements, just using a multifunctional mouse.

3.4.1 Navigation inside a block. This software allows the user to move inside the whole object space and automatically select the stereo-pairs of interest.

At the beginning, a 2D general view ("graphic index", e.g. an existing map or a photomosaic of the area) of the selected sub-project is displayed on the screen. The user just clicks onto the desired starting point and the software automatically loads the required stereo-pair: a 3D window appears and the floating mark follows the movements of the mouse (see figure 3).
Particular attention has been paid to obtaining a continuous movement inside the stereo-photomap: the user might not see the change of stereo-pairs during the navigation.
Let us consider the small block represented in figure 4: it can be freely explored in all directions.
Along the strip direction, when the floating mark moves from model 1 to model 2, the system swaps the left image of model 1 with the right image of model 2. Following the side direction, when moving form model 1 to model 5, the system swaps the two images of model 1 with the two images of model 5.
To avoid repeated swapping steps, the navigation software considers the overlapping area of two adjacent models (hatched areas in figure 4) and it swaps the images only when the floating mark is on the edge of the overlapping portion of the two models.
Figure 5 shows what happens along the strip, when the floating mark moves from model 1 to model 2: swapping occurs only in the case represented in figure 5a. If the mark returns, the images are swapped only when the edge shown in figure 5b is reached.
The operator can open more than one stereoscopic window at the same time: in this way he can explore the same part of the object at different zoom levels and/or at different epochs (see figure 6).

3.4.2 From aerial to terrestrial blocks and *vice versa*. When required, the system shows special symbols on the aerial images (see figure 7), illustrating the availability of terrestrial stereopairs, strips, or blocks. By clicking on one symbol, the user can load and explore the corresponding terrestrial images of the façades, always referred to the same absolute XYZ reference system. Despite this, the movements of the restitution mouse follow a local "terrestrial" X_t,Y_t,Z_t reference system: the X_t,Y_t plane fits on the façade, while Z_t represents the depth from the taking point.
On request, the system comes back to the aerial navigation. During the navigation in the terrestrial blocks the user can see his position both in the "general view" of the stereo-photomap and in the "general view" of the active terrestrial block.

3.4.3 Stereoscopic collimation of single points. Collimation and co-ordinate measurements of single points can be carried out by using one of two available procedures. When the operator moves in height, the first procedure moves both the images (the so called Helava principle, or 4-control procedure).

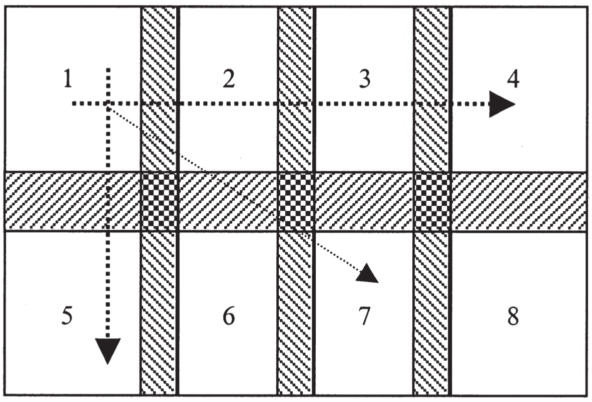

Figure 4. Example of a small photogrammetric block

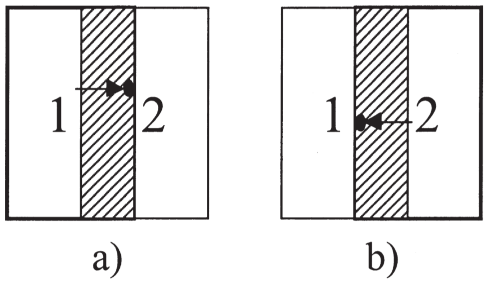

Figure 5. Swap technique

The second moves only one image (Inghilleri principle, or 2-control procedure) (see figure 8). This last option is easier for a non skilled operator: he can monoscopically collimate the wanted point on the fixed image and then eliminate the x-parallaxe by just looking at the homologous point on the other image, moved by the mouse. The computer automatically controls the y-parallaxe.
In both cases, the system uses matching algorithms, consisting in a pixel and sub-pixel correlation, in order to refine collimation and to achieve the required accuracy to compute X,Y and Z.
When the floating mark is far from the correct height on the model, the stereoscopic view disappears and the images appear doubled: for a non experienced operator it is difficult to acquire the stereoscopic view again. In these cases, a "help" function is available, which makes the system move automatically to the correct collimation of the nearest recorded point (e.g. one of the control points used to compute the orientation parameters or one of the points recorded during a previous working session).

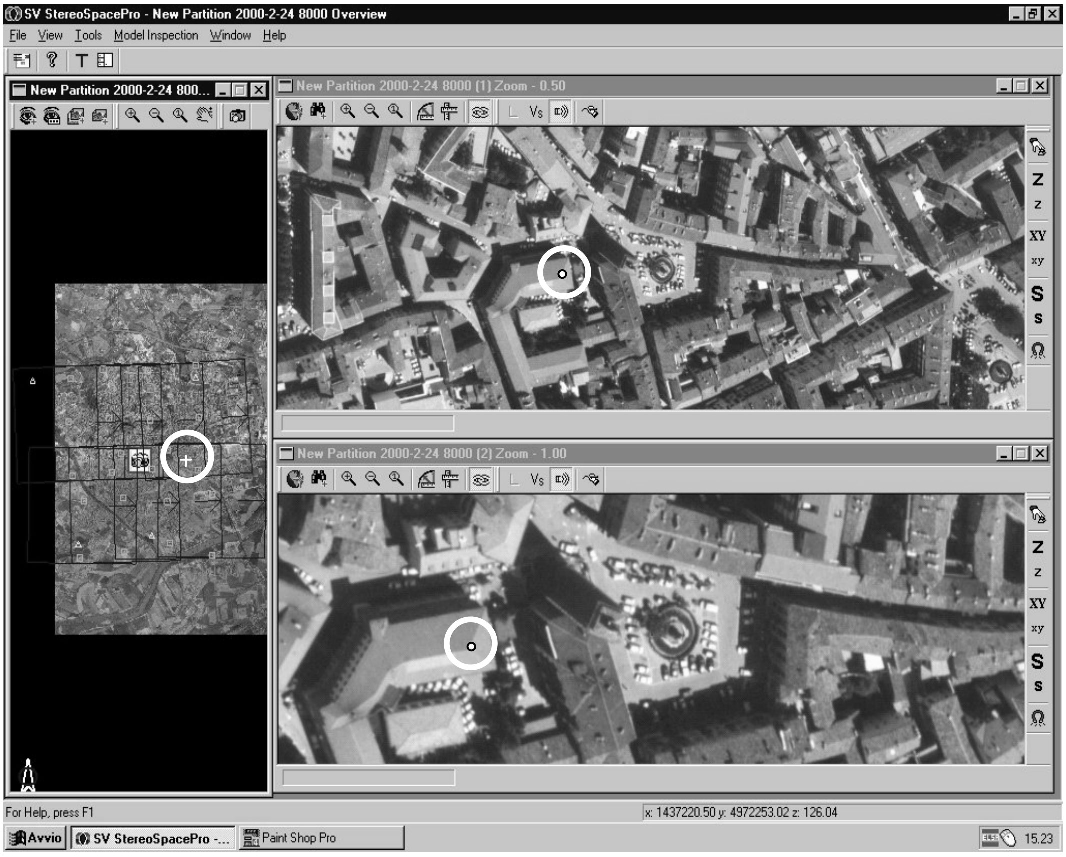

Figure 6. Windows showing the same area, with different zoom factors

Figure 7. Hot-spots joining aerial and terrestrial blocks

Figure 8. Stereoscopic collimation of single points in an aerial block

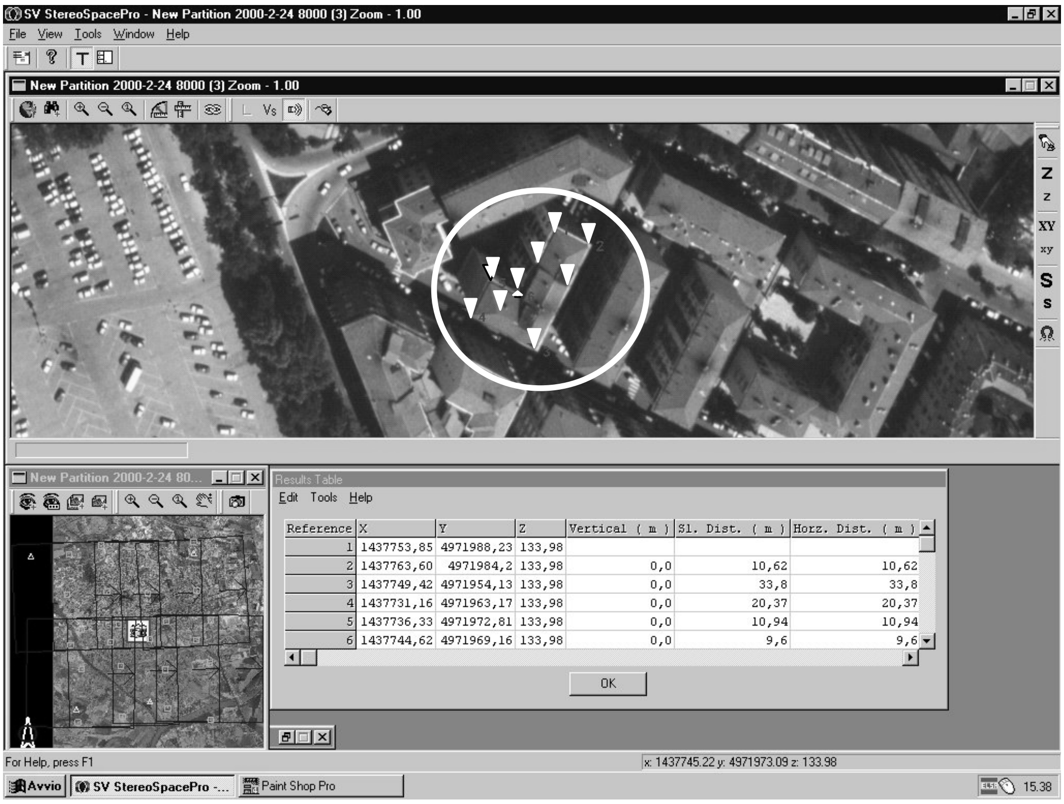

Figure 9. Co-ordinate recording of some selected points

3.4.4 Recording data. The X,Y and Z co-ordinates of the points selected by the operator (or X_t,Y_t and Z_t, on demand) can be recorded in an electronic sheet (for ex.. EXCEL, see figure 9); afterwards they can be used to compute required elements such as distances, areas, volumes or to generate drawings such as plane projections, perspectives, profiles, and so on.

4 CONCLUSIONS

The stereo-photomap concept and the 3D NAVIGATOR system greatly contribute to solve many of the problems that arise in the production of cartographic supports for different uses (environmental management, infrastructure design, etc.)
The stereo-photomap represents a new way of recording photogrammetric surveys. It is in fact an easy way to separate the different competencies required by a metric survey and its representation. Experts in photogrammetry have to plan and build the stereo-photomap, but they are not obliged to select the elements required for a correct reading of the object. In this sense the stereo-photomap is the natural 3D evolution of an orthophoto. As far as economic aspects are concerned, the production of a stereo-photomap costs only 30% that of a traditional digital map: only taking, scanning and aerial triangulation are in fact required.
The 3D NAVIGATOR is user friendly instrument able to inquire the stereo-photomap. A PC platform and a WINDOWS 98 environment make the use of this new instrument familiar to everyone. Thanks to the wide use of advanced digital photogrammetric techniques, the high degree of automation reached helps the user to become a good photogrammetric operator in a short time, without any previous knowledge of the photogrammetric process. The user has just to explore and select the elements that are useful to describe and understand the object. No care is required for measurement problems: the experts that have built the stereo-photomap have previously solved them.
The possibility of connecting aerial and terrestrial images is an additional performance of the system and a powerful tool of investigations for urban planning and architectural applications .
The 3D NAVIGATOR, as described in this paper, is a first step towards a new generation of digital photogrammetric instruments. Additional modules, such as stereo-plotting, DEM and ortophoto production, can be integrated with the 3D NAVIGATOR, to give the final user all the features available in a digital stereoplotter.
At the moment, the 3D NAVIGATOR is a “general purpose” instrument: in the foreseeable future specialised versions for specific applications (architecture, road design, map updating, etc.) will probably be conceived.

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