A PC-based stereoscopic measurement system for the generation of digital object models

Frank Boochs

FH Mainz, University of Applied Sciences, Germany
i3mainz, Institute for Spatial Information and Surveying Technology
boochs@geoinform.fh-mainz.de

Stephan Eckhardt

FH Mainz, University of Applied Sciences, Germany
i3mainz, Institute for Spatial Information and Surveying Technology
boochs@geoinform.fh-mainz.de

Ben Fischer

FH Mainz, University of Applied Sciences, Germany
i3mainz, Institute for Spatial Information and Surveying Technology
boochs@geoinform.fh-mainz.de

Abstract: A stereo system designed and used for the measurement of 3D-coordinates within metric stereo image pairs will be presented. First, the motivation for the development allowing to evaluate stereo images is shown. As the use and availability of digital metric images rapidly increases, corresponding equipment for the evaluation and measuring process is needed. Systems which have been developed up to now are either very special ones, founded on high end graphics workstations priced accordingly, or simple ones with restricted measuring functionality. A new conception will be shown, avoiding special high end graphics hardware but providing the measuring functionality required. The presented stereo system is based on PC-hardware equipped with a graphic board, uses an object oriented programming technique and allows a connection to CAD packages like AUTOCAD. The specific conception of the system is shown. The key role of OpenGL is described, which supplies some elementary graphic functions, being directly supported by graphic boards and thus provides the performance needed. Further, important aspects as modularity and hardware independence and their value for the solution are shown. Finally, the functionality of the software is presented in more detail.

Key words: Digital Photogrammetry, Photogrammetric workstation, Digital object model, Stereoscopy, 3D-Measurement, CAD, Object-orientation, OpenGL.

Introduction

Digital images are increasingly playing an important role in the photogrammetric business. Their primary advantage is to permit a higher degree of automation within evaluation processes. They of course allow additionally to apply conventional actions onto images like manual stereoscopic measurements, for example. However, the size of the images to be displayed during such interactive evaluation steps makes it necessary to have powerful computer equipment allowing to effectively handle all the data. Therefore conventional photogrammetric workstations are based on specialized graphic hardware with corresponding special software solutions. This concept is accompanied with high costs, dependency on proprietary hardware and low flexibility.

These disadvantages might be avoided by use of powerful standard hardware together with an open and modular software structure. This allows to reduce hardware costs, to simplify and accelerate the process of development and to adjust the functionality to different applications. For the domain of close range photogrammetry, for example, it might be of value to integrate existing CAD packages into an evaluation environment.

Based on the aspects of simplicity, modularity and flexibility a digital workstation has been designed and is under development. Further more, motivation and background for the proposed solution are outlined, the design of the system is sketched and some technical details are presented.

Photogrammetric tools

General

Since the end of the 70ies, photogrammetric instruments work under computer control and allow to generate digital object data. They are controlled by a human operator and meet all requirements for an efficient data collection system.

Actually, the technological step towards purely digital systems is ongoing. Digital systems have the advantage to contribute to the collection process by some automatic evaluation tools

exploiting the content of the digital data. However, their use for a complete 3D-data collection is restricted to objects being represented by a certain number of directly mounted targets. Here, adopted search algorithms can be applied allowing to detect the targets and to determine their positions in space. Under certain conditions even real-time applications are possible using integrated camera systems capturing the image data and automatically exploiting them by means of processes running on the integrated computer system (Imetric, 1999; Leica, 1998).

However, in general, purely digital systems need human control, at least for the collection of the object 3D-data. Then, one demand for these systems is to handle the image data during the 3D evaluation process. Typically, images may have sizes ranging from 10.000 by 10.000 pixel up to 30.000 by 30.000 pixel each. Accordingly, the work load for the computer system is high within all those steps dynamically accessing the image data.

Digital workstations

Conventional digital photogrammetric workstations support such huge digital images. They are generally based on powerful graphic workstations equipped with special viewer components needed for the stereoscopic perception process. Moreover the manufacturers often have adopted there software solutions to the special characteristics of these workstations in order to maximize the performance.

This leads to some disadvantages. The nature of these instruments causes
- high costs
- dependence on the specialized hardware and on the providing company
- low flexibility to technological changes

Most of these items are caused by the proprietary characteristic of the instruments. The manufacturer has to invest great effort into an own solution which has to be amortized. The customer has to rely on the provider and his capability to keep track with the technological process. Furthermore, third party solutions being available are hardly to integrate, because of the hardware dependence of most proprietary equipment.

Alternative

It seems promising to avoid hardware dependence. With respect to flexibility it is necessary to have a modular and open software structure allowing to substitute individual components as there are better ones available. Furthermore, one should try to found an approach on available standards and other open resources in order to reduce the development effort.

Nevertheless, the demanding characteristic of photogrammetric evaluation processes remains and has to be considered. In order to sketch just some of the needs, the following list gives an impression of the features to be met:
- allowing images of any size and depth (up to 900 Mpixel per image, B/W and color)
- fixed floating mark with moving image
- continuous, endless image move with different speeds
- single, double image and 3D-viewing measuring mode

- with appropriate interactive control features
- registration of all kinds of coordinates together with semantic object information
- ergonomic environment and an agreeable, not tiring stereoscopic viewing system

These requirements need considerable computer power and an adopted control and application software. On the other hand, the technological progress on the computer market is extremely high allowing to realize solutions based on standard PC systems.

Design of the PC-system

General

As conclusion from the deficiencies of specialized solutions we have tried to find a modular concept based on available standards and the corresponding resources. Fortunately, we can profit from the rapid development of the market of PC hardware and applications, which meanwhile even has produced components for a stereoscopic environment. Although this is driven by the game and virtual reality market it allows to choose a solution founded on standard PC components, which should be powerful enough to realize a 3D-measurement application. In order to keep a maximum of portability, device dependent control components have been avoided. This might result in a slight loss of capacity, but that should be acceptable in comparison to the cost of device dependency coming with specialized solutions. Stereoscopy and graphic control therefore are based on the VESA and OpenGL standards.

The aspect of portability is extended to the use of other operating systems than MIRCOSOFT™ based ones resulting in the need to have system specific software elements controlling the graphic devices. As it should not be subject to this project to develop system specialities it has been decided to incorporate the wxWindows Graphical User Interface (Smart, 1999). This provides all necessary routines for the installation of graphic solutions within different environments and additionally gives the corresponding look and feel.

Look and feeling is of supplementary value for the acceptance of the graphical interface by the user community. Once used to work on a PC one is in general familiar with MIRCOSOFT™ and the window technique utilized there. The acceptance of products coherently increases, if the interface seems to be well-known. The design of the graphical user interface takes these aspects into account and tries to provide simple and easy to use tools.

Hardware

Central part of the hardware is a Pentium III CPU with 500 MHz equipped with 512 MB memory. The CPU provides standard processing speed with respect to the actual PC generation. Of importance is the equipment with sufficient main memory, because the main work load during the measuring process comes from the transportation of image data. Here a large intermediate buffer is necessary, to avoid waiting periods induced by the slow access to the mass storage. The selected amount of

memory seems to be a minimum quantity required. Correspondingly the amount of mass storage should not fall beyond 5GB, as standard projects may require up to 3 GB storage capacity (cf. Fig. 1).

Stereoscopy is based on a powerful graphic device (ELSA Gloria XL) a stereo monitor and stereo glasses (Stereographics® CrystalEyes®) with appropriate control. The graphic device shows up some features, which are important for a 3D-measuremnt environment:

- high resolution (up to 1280*1024 true color mode)
- VESA interface for direct connection to stereo glasses
- hardware acceleration for several OpenGL-functions
- stereo-in-window technique
- stereo refresh rate up to 120Hz

This graphic card is one representative of a new generation of graphic boards widely supporting OpenGL functionality onboard and being designed for stereoscopic applications. Their appearance will increase in the future allowing to choose between several alternatives, if a software is founded on a graphic standard like OpenGL.

Of interest for our solution are the direct support of stereo glasses, the high refresh rate guaranteeing flicker free stereo viewing and the stereo-in-window technique. The latter has some advantages compared to the standard above-below stereo solutions, which are splitting the screen in a top and bottom part each containing one of the stereo images. By this the whole screen is affected and can only be operated in stereo or non stereo mode avoiding to simply mix different windows on the screen. Furthermore, there is a loss of 50% resolution. Both drawbacks are avoided with the stereo-in-window principle, which is possible due to the stereo mode available in OpenGL. This means to have a quad buffered window, where front and back buffer are split into two pieces each referenced to one image of the stereo pair. Finally, we have the hardware acceleration provided by the board, what of course is very useful, although software solutions would do their task likewise.

Software

Design aspects

Concluding from the deficiencies of specialized solutions we use a modular concept based on available standards and corresponding resources. With respect to the display of images and handling of graphic data, for example, we use the most common standard: OpenGL. All available system platforms have at least a software solution for OpenGL and many graphic boards provide on board intelligence giving the acceleration needed for an acceptable measuring environment.

As OpenGL is supported by all common computer systems, this offers the opportunity to build a solution being independent from the manufacturer. However, the graphical user interface then has to be developed independent from the system environment too. In general, this causes some additional efforts, because UNIX and MICROSOFT™ use different graphic software. But fortunately developments from other sides handling the problem of graphic interfaces in different computer environments do exist. One very powerful solution is the wxWindows Graphical User Interface[1]. It is an object oriented software package providing all necessary components to build user interfaces and is founded on system dependent libraries. This assures the look and feel the user expects and allows to install the same package on differing computer environments simply by exchanging the underlying graphic library. The user community of this package permanently grows and ranges from scientific users to ones[2].

The use of OpenGL and wxWindows assures the requirements coming from the wish to avoid hardware dependency, to be flexible to the technological progress and to exchange components, if necessary, or to incorporate new ones. Based on these standards now an application software has to be built, which has to fulfil very different functional needs (cf. Fig. 2), should reduce the effort for maintenance and modifications and should allow to compose packages being optimally structured to serve different type of applications. As a consequence, there is only one way to support all these wishes, that is to use an object oriented programming approach within C++. This language combines the advantages of object orientation with the possibility to incorporate time effective functions written in C.

Photogrammetry

Several tasks have to be performed when a photogrammetric project has to be handled:
- Project set up
- Interior orientation
- Exterior orientation
- Generation of stereo image pairs
- 3D data evaluation

This list looks very conventional for a photogrammetric processing chain, but it might need much more effort than just handling two images forming a stereo model, which will be used for the data evaluation. Therefore, some aspects will be mentioned documenting the flexible nature of the software developed.

The set up allows to store all necessary external information (point coordinates, calibration values,...) available and has to introduce the control of the following processing steps. Here flexibility is expressed by
- the number of images, which might be processed simultaneously. This number has to be only restricted by the available storage capacity
- the type of external information usable. Types have to be extended to the use of any kind of geodetic data, allowing to process distances, angles, geometric constraints and so on.

The step of the interior orientation comprises the measurement of the fiducial marks and the calculation of the geometric relation between camera system and digital system. Here additional performance is introduced, when the system allows any kind of camera type. This makes it necessary to process reseau camera data or image geometries differing from the normal central perspective model.

The step of the exterior orientation is very simple, if there exist simply one image pair. This is not necessarily the standard situation, when surveying objects of any type. Conventionally, objects are observed by several images capturing all the parts having to be geometrically evaluated (cf. Fig.3). It's then the job of this orientation step to combine all images into a stable and fixed image block. The only way to do this is the measurement of tie and pass points expressing image rays which have to intersect and to hit the object at the same position. In principle, this might not appear as a demanding step, but if one considers, that

- images have different perspectives
- images might be exposed under differing illuminations
- most object points are signalized
- objects show occlusions and discontinuities
  the process of measuring tie and pass points obviously is difficult and possibly needs some iterations until good points are found.

The generation of stereo image pairs is indispensable, because, except of standard aerial image blocks, images forming a model allowing to perceive the data stereoscopically do not exist. Therefore one has to introduce a processing step, which generates epipolar image pairs serving as visual basis for the 3D-evaluation procedure (cf. Fig. 4).

Finally, there is the 3D-evaluation process. Here, challenges come from the fact, that the measuring environment has to fulfil the needs of a photogrammetric workplace. For example, photogrammetric operators expect to have certain control elements allowing to move through the 3D-space. They await to find the floating mark pointing to the object details resting fixed in the middle of the viewer. This makes it necessary to permanently move through the image space, which means to shift the image data continuously through the viewer – a challenging aspect, having the amount of image data in mind, which has to be handled.

The amount of image data, in general, introduces hard challenges. The storage amount of aerial images starts with moderate 21 MB (50 mòm Pixel, B/W image) and ends with 1587 MB (10 mòm Pixel, color image), when the image is prepared for an interactive evaluation, needing to provide all necessary information details. This data has to be processed during the 3D-evaluation without any narrowing of the movement during the measuring procedure. The step of continuous measuring therefore need an intelligent solution for the image display.

Solution aspects

Image Loading

First, a decision had to be found, how the data can be accessed with maximum speed. Several other photogrammetric packages use proprietary formats designed to easily get access to the image data. This doesn't seem to be necessary, because there exist an efficient format with tools available for data transfer: TIFF. We use TIFF, as it allows to hold all formats one can imagine. It's even possible to create an own format. In its latest version, TIFF does already provide everything needed to implement the loading component. Furthermore, TIFF is supported by most conventional image processing tools, what simplifies the data conversion from or to other sources and avoids the need to develop own conversion tools. TIFF is even flexible enough to load the images in tiles, which is inevitable with the large images sizes to be handled. With tiles one is free to load as much of the image as necessary, but not more, thus reducing the memory load of the application. Sam Leffler's libtiff library[7] already comes with a small tool to tile existing TIFF images. This step is sometimes necessary in order to convert external TIFF data into tiled one, because this is not necessarily supported by all image processing tools.

With respect to the size of the tiles, experience has shown, that 256 x 256 pixels for each tile are an adequate compromise between storage load and transfer speed. Other sizes are possible, but up to now there is no need to select a different one. Within the measure component the one class (AerialImage) is responsible to handle these tiled TIFF images. Fortunately, the libtiff library already offers all functionality to load single tiles from a tiled image so one just has to map the corresponding libtiff functions to methods of class AerialImage. Additionally, the AerialImage class holds a tile table to handle the memory addresses of already loaded tiles.

Image Display

Once the image file is tiled it's possible to load just those tiles needed to fill the viewport within the display window. (cf. Fig. 5). The TileManager class is responsible to manage the tiles in memory. After creation of the display window and the OpenGL viewport within this window the TileManager class calculates the number of tiles necessary to fill the viewport. It will recalculate the number every time the user resizes the display window. Next, it selects the tiles to be displayed and loads them. Then, this object waits for user interaction. When the image is moved by the operator, this will be registered by the TileManager class. Dependent on the actual viewer position, it decides whether it is necessary to load new tiles and to destroy old tiles or if the already displayed area of tiles has still enough data to fill the viewport. All image movement directions are handled separately. That means positive X, negative X, positive Y and negative Y movement is handled separately. As a result, the steps necessary to move the image just have to be done for one direction.

This buffering procedure assures that the main memory always holds enough data, when further movement in the negative X direction occurs and new image information has to be loaded into the viewport. Obviously, there are only a few instructions necessary to handle image movement. To actually display the tiles within the viewport there're just two loops over the tile area needed (cf. Figure 5), one to display the rows and one to display the columns. OpenGL can handle raw pixel data directly so there is no need for further calculations or conversation. Experience has shown, that drawing raw pixel data works better than using textures. These two concepts, few instructions for image movement together with fast raw pixel display using OpenGL results in very high display speed even on standard PC hardware.

Stereoscopic Viewing

The OpenGL standard has built -in support for stereoscopic view of rendered content. Using this build-in functionality it's quite easy to get a stereoscopic view of stereo images. As all functionality to display images is encapsulated in the TileManager class it's relative straightforward to extend this class to handle stereo images. There're four things one has to take care of, when rendering stereo images.

- a stereo hardware environment is needed. That means a graphics card that supports stereoscopic view and some equipment to separate the left image for the left eye and the right image for the right eye (We use shutter glasses for image separation)
- a stereoscopic window is needed. Some operating systems and graphic card drivers support the stereo-in-window technique, where the stereoscopic view is restricted to just one window and not the whole screen (We use this technique under Windows NT)
- one has to render the content twice. Once for the left image and once for the right image (The TileManager class of the measure component handles this)
- one has to apply an offset between the left and the right image to actually create the stereo effect (The TileManager class of the measure component handles this)

So, the modular structure of the software supported by the graphics standard selected allows easily to extend the whole image management to stereoscopic images and therefore assures an effective handling of large data sets even in stereo mode and provides the functionality needed for a powerful measurement environment.

Simultaneous viewing of multiple images

For the majority of terrestrial applications images are taken in blocks surrounding the object in question. Prior to any three dimensional measurements the images need to be oriented and then transformed into epipolar image pairs allowing to view stereoscopically. The step of orientation simply needs some measurements of tie and -if available- pass points. However, this produces some problems, if the object is neither equipped with point signals nor showing enough details allowing to clearly and unambiguously identify points.

A simple solution for such difficulties is possible, if the selection, identification and measurement of the points will be done in all images simultaneously. Then a visual comparison of the object as it is represented in those images covering the same part allows to carefully select and identify identical points, avoiding errors due to wrong interpretations. In order to achieve this, all images have to be managed at the same time. This produces a lot more effort from the side of programming, because one has to handle multiple images, with multiple object points, each having multiple image measurements at one time. However, such a conception is very lucrative, because it increases the flexibility of the program and allows to handle any constellation of images and measurements therein.

Fig. 6 shows the environment for the measurement of tie and control points as arising from 4 images. Within the image frame all images available in the project are listed. This allows to control which images are displayed and gives the possibility to interactively change the active images. All images active have an overview frame. By means of these frames the navigation through all images of interest will be done, when looking for an appropriate object point. For the measurement, the image to be treated is loaded into one of two measure frames. This frame has the resolution needed for an accurate measurement and is used for the collection of the coordinates. The results of the data collection are displayed in the control frame. Here, the user finds the point, which has been selected for the measurement , the name of the active image and the coordinate values. Finally, there exists the point frame. Here available object points are listed. They may come from previous definitions of new tie points or may be introduced as pass points.

Conclusion

A modular conception based on graphic standards has been presented allowing to handle digital photogrammetric image blocks, to produce stereoscopic image pairs and to compile them performing 3D-measurements in the virtual 3D space spanned by these models. The use of the OpenGL standard even permits to use hardware acceleration providing high processing speed. Furthermore, standardization allows to incorporate from third party most of the graphic functionality necessary for user dialogs and image viewing processes, considerably reducing the effort of development. An intelligent image handling drops the amount of data transfer to the inevitable minimum and permits to handle very large images as they can only conventionally be handled within specific photogrammetric workstations.

This shows, that the use of standards together with a modular object oriented approach provides a performance up to now being reserved to high end photogrammetric workstations.

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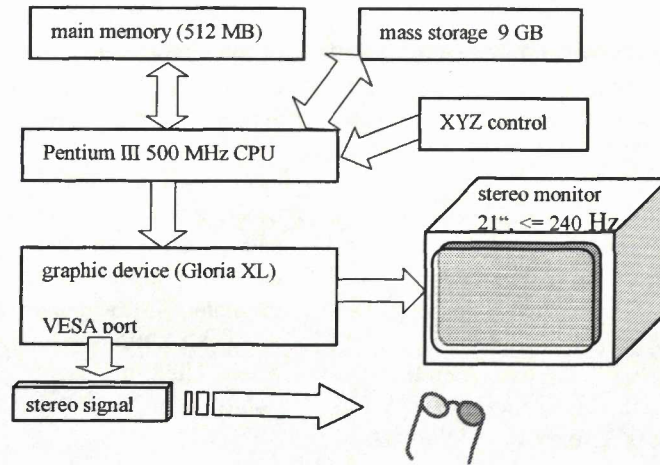http://www.wxwindows.org

Figures

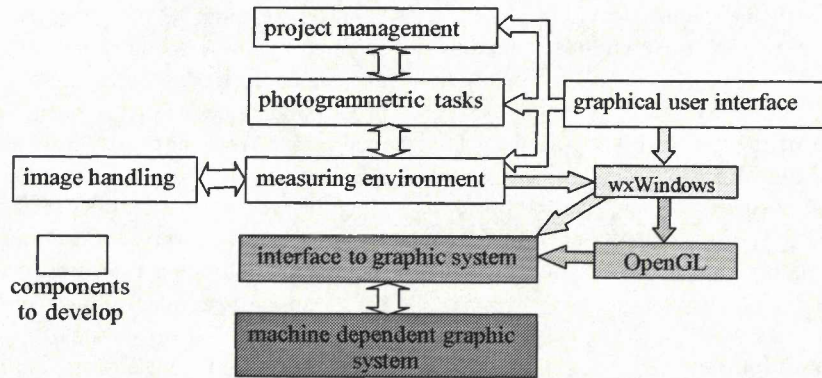*Figure 1: system components*

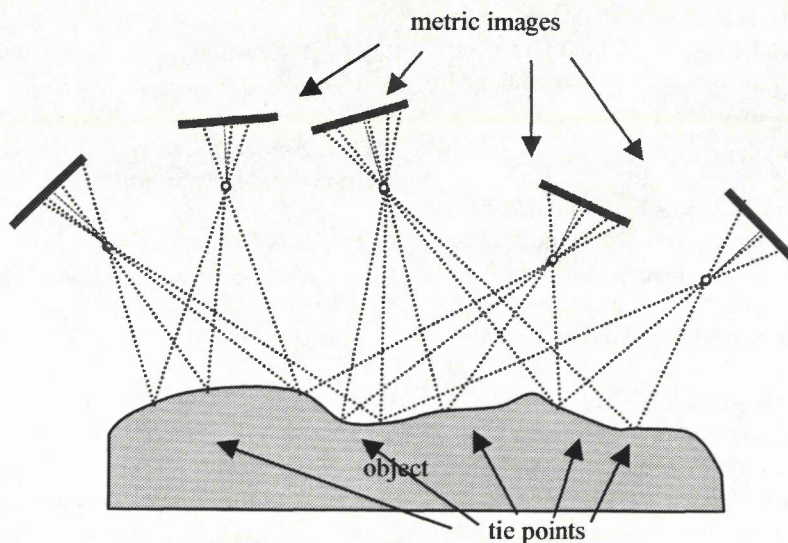*Figure 2: software components*

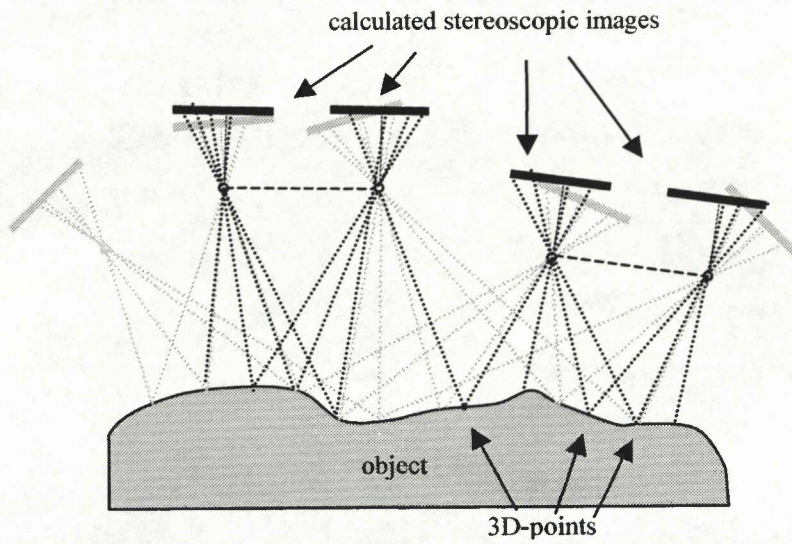*Figure 3: photogrammetric images forming a small block*

Figure 4: *Generated stereoscopic image pairs used for 3D-*
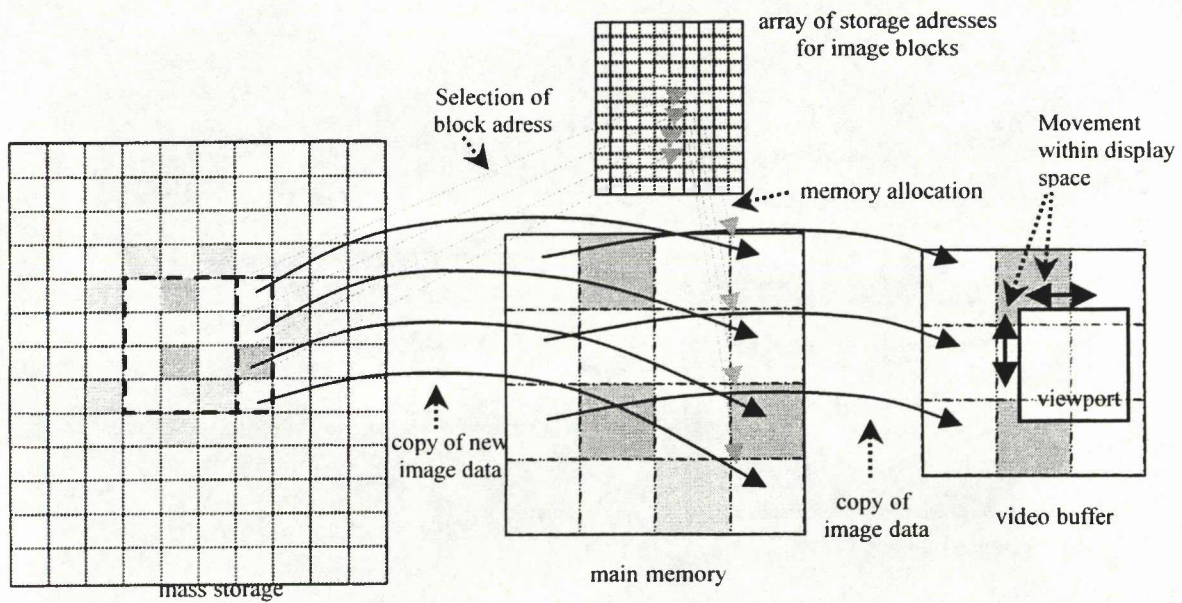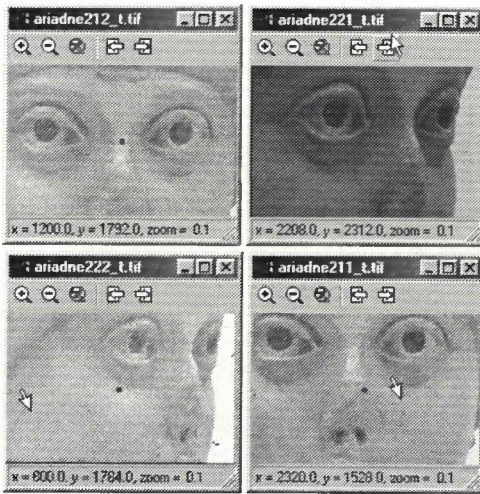

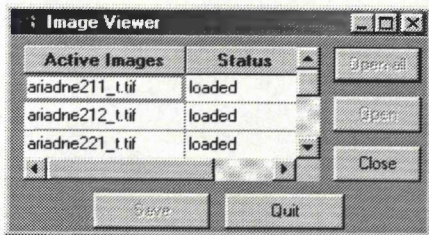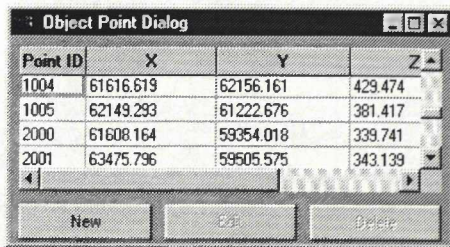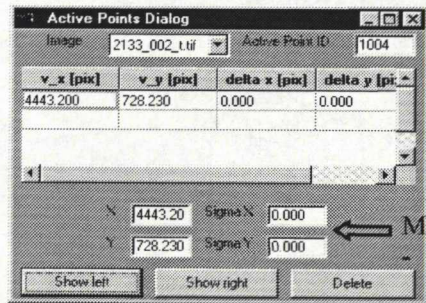Figure 5. *Dynamic handling of image data*

Overview frames

Image frame

Measure frame

Point frame

Control frame

Figure 6: Environment for tie and cointrol point measurement