REQUIREMENTS OF A STEREO WORKSTATION FOR GIS ENVIRONMENT

Tapani Sarjakoski and Jussi Lammi

Finnish Geodetic Institute
Ilmalankatu 1 A
SF-00240 Helsinki
Finland

Commission II

ABSTRACT

Integration of digital stereo images into GIS databases offers new possibilities for the end-users. This paper studies the requirements of astereo workstation needed in this utilization. The basic requirements of a stereo workstation are the capability for stereoscopic viewing and possibility to do precise 3D measurements. Especially in the GIS environment the demand to display and edit vector formatted 3D data as conveniently as possible becomes important. Implementation of a stereo workstation allows a variety of solutions both in hardware and in functional sense. Nowadays stereo displays are off-the-self products and they can be added to the existing graphic workstations. General guidelines for a stereo workstation design are given and implementation of an experimental stereo workstation is discussed.

KEYWORDS: Stereo workstation, GIS, Digital imagery, User interface.

1. INTRODUCTION - STEREO IMAGERY IN GIS ENVIRONMENT

Figure 1 illustrates the principle how digital stereo imagery should be used in GIS environment. Digital imagery is stored as a part of a GIS database, to be used in combination with 3D data. Workstations with stereoscopic viewing systems are used for interactive interpretation and mensuration purposes. A production phase in which the analog images are digitized and geometry is determined is a prerequisite for storing the images in a GIS database.
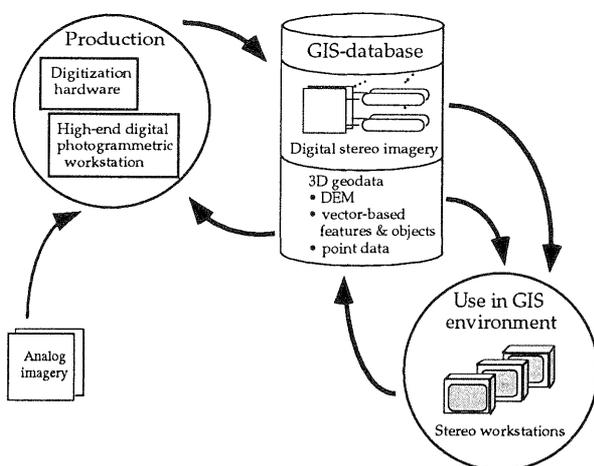

Figure 1. Production and use of digital stereo imagery in GIS environment.

This scenario is a part of the general trend of hybrid GIS approaches in which raster-formatted image data and vector-formatted feature data are used jointly (see e.g. Fritsch, 1988). Relating this to the use of digitized aerial photographs, it is often stated that digital orthophotos will become the most important mode of use. Urban environment, however, is demanding regarding the production and use of digital orthophotos. Urban environment is human-made. It contains a lot of objects that are clearly three-dimensional. Vertical faces are rather a rule than an exception. They cause many shades to appear on aerial photographs. It is thus a demanding task to produce an orthophoto which is positionally accurate for all the details (Bähr &Wiesel, 1991). A complex or complete DEM (digital elevation model) or even a complete 3D DTM (digital terrain model) would be required. Digital orthophoto imagery always lacks of 3D information, which puts it in contrast with digital stereo imagery.

To summarize, stereo imagery based on digitized color photographs seems to be very suitable to be incorporated in urban GIS databases for the following reasons:

- Digital orthophoto is not always feasible because it does not contain 3D information.

- Production of digital stereo imagery does not require digital elevation model. In this aspect, digital orthophotos are much more demanding because a "complete" 3D elevation model is necessary.

- Color information is important for visual

interpretation purposes, especially when digitized material is used on occasional basis by non-professional image interpreters. From economical point this is also feasible as the marginal costs of color photography, compared to black-and-white, are rather low today.

Stereo workstation is a prerequisite for utilizing digital stereo imageries in interactive manner. The technology for stereo workstation is available and several photogrammetric stereo workstations have been designed and implemented (see e.g. the review by Dowman, 1991).

The objective of this paper is to study requirements of a stereo workstation when it is targeted to be a tool for an end-user of digital stereo imagery in GIS environment. In this respect we want to further promote the "democratization of photogrammetry" (Leberl, 1991) We try to define general design principles and we also summarize ideas presented earlier by us (Sarjakoski, 1990; Sarjakoski & Lammi, 1991; Lammi, 1992).

2. ENVIRONMENTAL SETUP FOR WORKSTATION DESIGN

Personal-computer based text processing have radically changed our attitude towards the production of "typewriter-quality" text and publishing: typing was considered as a profession and the technicalities of making printing originals were often considered as an obstacle for making printed publications. Today we hardly have any typist in an office, rather, there is a "multi-job" secretary who might help in finishing of the machine-readable documents made by the experts in various fields. The desktop publishing software has made the conventional typing fully obsolete in many areas and reduced the costs significantly.

We claim that easy-to-use stereo workstations integrated with geographical information systems will have impacts comparable to the described changes above. Interpretation and mensuration of stereo photographs will be made by non-professional "operators" - to a great extent. Photogrammetric data collection will not be regarded as a mapping project but rather just-on-time (JOT) principle will be followed in data collection.

The attitude towards stereo workstations will be in future very much the same as it is towards office automation today. Environmental setup will be such that

- Each user has his own workstation (read: a man-machine interface to a computing device, consisting at least of a graphics display, a keyboard and a mouse).

- The price of the workstation is so low that it is economically appropriate to supply each user with his own workstation, even if he does not use it continuously.

- All the necessary pieces of software is accessed thorough this interface.

- Many pieces of the software are integrated to be part of larger information systems.

- All the software follow a uniform interface design principle or standard (Motif, Windows, Apple windows, SunView etc.).

- The systems must be so easy-to-use that the necessary training time is not more than one hour - one day, assuming the user already has a basic understanding of the application domain.

Stereo workstation must now be a functional extension of this single, multipurpose workstation. The necessary hardware extensions should be minimal.

3. FEASIBLE HARDWARE SOLUTIONS

The analysis of the requirements of a stereo workstation in GIS environment should be started from the analysis of functional requirements. To lay out a foundation for this work, the feasible hardware configurations of sterero workstations are here reviewed in the light of current and near-future technology.

3.1 Stereoscopic display systems

Practically, there are three realistic alternatives for stereoscopic display system - one of them is based on the optical split of the screen while the other two approaches use the polarization technique. Difference between the polarization methods is in the type of used polarization and in the technique of realization. Stereoscopic viewing in these polarization based approaches is done either by using passive glasses and circular polarization or active glasses and linear polarization. Both of these methods enable free viewing of the stereomodel while optical split is always tied on the used mirror system.

3.1.1 Optical split of the screen A familiar example of the optical split is a mirror stereoscope - stationary analog images are viewed through oculars and the mirror system of the instrument forces left eye to see the left image and right eye to see the right one. The idea is exactly the same with this type of stereoscopic display system only the images are changed to the digital ones. Both images of the stereopair are shown all the time on the screen (or screens) and they are viewed through a mirror stereoscope in front of the display.

3.1.2 Polarization approach with passive glasses In the polarization approach with passive glasses the images of the stereopair are alternately shown on the display. A screen-sized liquid crystal modulator - synchronized to alternation with the graphics hardware - provides different polarization for left and right eye images. Special polarizing glasses worn by the operator decode the polarized images correspondingly to the left and right eye. This kind of a stereoscopic display system is realized and manufactured by

Tektronix. Images are handled in interlaced mode, i.e., the other image is displayed on the odd and the other one on the even lines of the display. This, of course, decreases the quality of the stereomodel.

3.1.3 Polarization approach with active glasses

The technique in this approach is very much the same as it was in the approach with passive glasses. Again a time multiplexed stereopair is shown on the display but this time the shutter is mounted into a pair of active glasses. The active system contains two linear polarizers for both eyes. Between them is a liquid-crystal cell which can rotate light by 90° so that light meant to the right eye only is blocked from the left eye. Realization of this approach is done by StereoGraphics Corporation with CrystalEyes system. The liquid crystal cells are synchronized to the refresh rate of the monitor via a wireless infrared link.

3.1.4 Use of stereoscopic display systems

In Table 1. we have listed the effect of different stereoscopic display systems on various design aspects. Note that when display systems are discussed in general there is also other things to be considered, these include e.g. optimal size of the screen (physical dimensions), dot-size and available colors (full-color, grey-scale).

There are a lot of applications where stereoscopic display systems are not necessary. Even some of the tasks that benefit from the use of stereoscopy can also be done without it. There also exist people who cannot see stereoscopically. In all these cases the chosen stereoscopic display system should not disturb other work. We believe that stereo workstations based on multiple screens are preferable in this sense. They give the best support for the multipurpose principle of the workstation: all existing software may be used without modifications, even simultaneously with the "stereo software" (or even stereoscopic viewing) under the window system.

3.2 Three-dimensional control

Three-dimensional control over 3D object data is required from the stereo workstation. Ergonomy and suitability of the three-dimensional control device greatly affects to the usability of the stereo workstation. The control device itself can be a single device or a combination of two or more devices, possible choices are e.g. keyboards, mice, trackballs, joysticks, footwheels, lightpens, touchscreens, digitization pads, digitizing gages, datagloves. Typically each of these device produce increments in some device-dependent coordinate system - how the increments are interpreted depends on the used software.

Although a variety of different possibilities are available for three-dimensional control, already a very modest configuration is adequate. These "basic" configurations include e.g. a mouse or digitization tablet with buttons for height control (as e.g. in the DVP, Nolette et al., 1992).

3.3 Capacity of future workstations

It has been forecasted in a paper by Frank et al. (1991) that in the late 90s we may see the following specifications for a personal GIS workstation:

- a CPU with 500 MIPS,
- 500 Megabytes of main memory,
- 5 Gigabytes of storage space on hard disks an additional 50 Gigabytes on optical disk,
- a workstation screen with 2000 by 2000 pixels and
- a communication device with 100 Megabytes per second transfer rate.

Moreover, they expect that a workstation with these capabilities will cost about the same as today's personal computer with moderate capabilities.

Table 1. The effect of different stereoscopic display systems on various design aspects

	Polarization with passive glasses (Tektronix)	Polarization with active glasses (CrystalEyes)	Optical split of the screen
Free stereoscopic viewing	yes	yes	no
Enable multiple viewers in stereoscopic mode	yes	yes	no
Image resolution in stereoscopic mode	1/2	1/2	full
Multiple screens mandatory	no	no	no (yes)
Multiple screens in simultaneous use	possible	not possible, due to flickering	possible
Support for multiple, simultaneous programs	yes, but realistic only if multiple screens	no, because mono windows cannot be used with stereo	yes, with multiple screens

The progress in computer technology today is so fast that the forecast above can be considered to be realistic. It also indicates that stereo workstations should be based on a personal-computer principle, i.e., the CPU is dedicated for the tasks of a single user. It guarantees flexibility and an immediate access time even if the whole system is loaded.

4. FUNCTIONALITY

The basic functional principle of a stereo workstation is simple (almost naive): we have to be able to edit 3D object data that is projected on images. The 3D object data is related to the physical, three-dimensional reality. This does not mean that 3D object data is all the time consistent with the physical reality, depending on the consistency the following types of 3D object data can be found:

- Old data. This was relevant in the past but now the reality has changed.

- Current data. This is consistent with the reality.

- Data of planned situation. This type of data describes the physical reality in the future.

We need only three different tools to achieve the required functionality, those tools are create object, delete object and modify object. As a matter of fact, even the modification tool is unnecessary because all objects can be modified by first deleting them and then creating again in a modified form. However, this approach is not very intuitive and it is also wrong if the identity of the object instance is wanted to be preserved.

The actual editing of 3D object data can be done in many ways depending on how the object parameters are given and who is in charge for editing. In this context we divide editing modes into four groups: stereoscopic editing, image-wise editing, editing with automatic height control and automatic editing. Stereoscopic editing is done when stereoscopic vision is used for editing of 3D object data. Editing becomes image-wise when two or more images are used independently for editing. Editing with automatic height control is an example of semi-automatic approach - user selects the targets to be correlated and the correlation process gets the match from one or more images. Automatic editing is in case when 3D objects are edited without manual intervention.

5. IMPORTANT TECHNICAL ISSUES

5.1 Viewing tools and windowing

Because the technique used in stereo workstations is different from the one used in analytical plotters, some differences will also arise in use. In analytical plotters we have easily used the technique of fixed measuring marks, moving images but in the stereo workstations the paradigm of fixed view, moving graphics is the one in prevail. The approach of fixed view, moving graphics

is not only more economic to realize than the approach of fixed measuring point, moving images but in the case of free stereoscopic viewing it is also more ergonomic and more intuitive. Stereo workstations also contain a lot of possibilities embedded. A good example is the superimposition of graphics which is an expensive accessory in analytical plotters but which is always available in each window of the stereo workstation.

Although the actual work is done on a fixed view, a new fixed area has to be accessed within a reasonable time. However, there is no real-time requirement on the change of the viewing area. Typically the change of the viewing area could be done e.g. by pointing the area of interest from an overview image or by using the scroll bars (or side rulers) in the windows. In some cases it could be wise to allow automatic change of the fixed view on edges of the fixed viewing area - when edges are confronted, change is automatically done. In case the update of images is realized very fast, the illusion of moving images might be given. Note that all these methods are supposed to be served as alternatives for the user - they do not exclude each other.

It is almost self-evident that stereo workstations have to be designed on the principle of multiply windows. This approach is already familiar from many applications, such as text processing, graphics or drawing programs and 3D CAD programs.

In the approach of multiply windows, there seems to be a need for at least following windows: overview, mono, stereo and zoom window. Any of these can be hidden until needed. The overview window contains an image from the whole working area in low resolution, it enables quick change of the viewing area and makes the general location easier. Images in mono windows are used for all work that does not require stereoscopic viewing. Beside orthophotos, also the left and right image of the stereopair are shown in mono windows for image-wise editing. Images of the stereopair are show on the stereo window in such an relation as the used stereoscopic display system requires. Usually the position of the stereo window is strictly tied on the dimensions of the monitor and can not be moved from this position. To enable a closer look of images, a special zoom windows have to be provided. In our opinion, this is a better approach than the direct use of mono or stereo windows for zoomed images because good control of the neighborhood of the zoomed area is never lost. When 3D objects are edited the results of the editing should be projected to all windows containing the object in hand.

5.2 Tools for manipulating graphical objects

To give an idea of how to change the conventional ways of measuring to more flexible ones, we shortly describe the manipulation of graphical objects in stereo workstations. A variety of commercial design/drawing software have achieved such a functional maturity in object data manipulation that they should, in some extent, be taken as a model while designing tools for stereo workstations. Some of the principles used in these software seem to be even so good and commonly accepted that it is hard to suggest any better alternative for

interactive work in stereo workstations. When these techniques are taken into use in mapping applications, collection and maintenance of object data becomes as easy as the use of common drawing programs. Good examples of advanced design/drawing software are e.g. Intergraph's Microstation, Deneba's Canvas or Adobe's Illustrator.

Interactive drawing programs, based on the use of object graphics, work with a very simple principle. Although there exists a variety of different object types (e.g. point, line, polygon, closed polygon, rectangle or solid), the way of editing is very much the same in each case. A set of tools or functions are provided for the user in a menubar or similar. Depending on the type of the function, a tool can either be used directly as such (create object) or it may require that user has activated an object or group of objects into which the tool is applied (delete object, modify object). In the latter case, object activation is done e.g. by pointing a graphical object with cursor.

In the case of stereo workstations some automation is possible in tools. Beside completely automatic tools, some semi-automation can easily be realized (controlled data collection). The most obvious is a tool for automatic height determination when an object is located manually in one of the images. Because the actual work is done in GIS related applications, a sufficient amount of topology related tools have to be either embedded or available in tools (e.g. snap to an neighbor object). In all cases, even with the most advanced object manipulation tools, the editing principles adopted from the design/drawing software are valid.

5.3 Graphics superimposition

The graphical display of object data on the image is called superimposition of data. When stereoscopic viewing is concerned we can correspondingly speak of stereoscopic superimposition. Generally the overlay of graphics is done with fully covering wireframe techniques. It is likely that superimposition of wireframes only is not optimal for visual perception and when purely covering colors are used, vision of the image parts under the graphics is blocked. An alternative for pure superimposition is the use of such a transparent overlay that enable vision of image through graphics.

Transparent graphical layer for an image can be achieved by transforming the image into another color space than RGB and doing the overlay of graphics in this new color space. The applied color space transformation have to be such that it separates the luminance and chrominance values of the image. Selected objects are then drawn into the chrominance channels keeping the luminance unchanged. The inverse transformation applied to this image gives the superimposed result. If this type of transparent overlays are used it becomes necessary to manipulate the pixel values of digital images directly. This requirement makes it clear that only copies of original images are used and these used copies never saved over the originals.

The IHS color space is one possibility to do transparent overlays. The components of this color coordinate system - intensity, hue and saturation - are easy to perceive because of the similarity to human vision. Actually there are quite many color spaces (e.g. HLS, HSB and HSV) that have same or similar concepts but they normally differ from the IHS model by the used coordinate system (Foley et al., 1990: 590-595). In all cases the intensity (luminance, brightness, value) is kept unchanged, while the values in hue and saturation are changed for transparent superimposition. Beside these color spaces, it could be interesting to test properties of some direct transformations from RGB space to another Cartesian 3D color space. These color spaces include the YUV- and YIQ -color models (Foley et al., 1990: 589-590).

The use of transparent graphical superimposition does not mean that wireframes may not be used at all. On the contrary, both of these techniques are used so that the best possible result is achieved. It seems quite reasonable that even the transparent objects are enclosed by wireframe graphics. Proper antialiasing techniques have to be used for quality superimposition of edges.

5.4 Sub-pixel accuracy

It is well known that objects can be measured from digital images with sub-pixel accuracy. However, many of the used numerical techniques are devoted for automatic interpretation and measuring of targets (tie points, control points) that are not interesting in the sense of interactive GIS applications. The methods we discuss here are merely devoted for sub-pixel superimposition of graphical objects.

Sub-pixel accuracy can be achieved by performing real-time resampling of images on some interval less than a pixel. Use of this technique expects that a fixed measuring mark is used instead of moving graphics. In realizations with moving graphics a method for sub-pixel pointing is e.g. the use of a set of convolved cursors where "the system automatically selects the cursor that best represents the sub-pixel position at any moment" (Helava, 1991).

One of the most straightforward method to achieve the sub-pixel accuracy in interactive work is the idea of visual interpolation. When the graphical objects are superimposed on the image the position of any object will be observed by a human by integrating the object visually into its surroundings. The best possible fit of these objects can be achieved by editing necessary objects so that the neighborhood supports the fit visually. The sub-pixel pointing can be embedded in the graphics routines: graphical objects to be edited are forced to move in smaller steps than one pixel. This moving in sub-pixel steps is easy to realize inside the drawing routines of graphical objects. Similar kind of idea is used if antialiasing techniques are used for moving in sub-pixel steps. This antialiasing approach is, however, a somewhat questionable because background under the graphics is already fuzzy.

Although the problem of sub-pixel accuracy is interesting, its real importance should not be overemphasized. In our opinion an accuracy of about 0.5 - 0.25 pixel is the level that is supposed to be get from the stereo workstation.

5.5 Integration to other applications

In this article a stereo workstation is regarded as an interface to a Geo database. It is also assumed that it is used simultaneously with other applications like task-specific planning software. This necessities fluent flow of data between the system components. Figure 2 illustrates the situation. For the purpose of integration it is important that the communication between the systems is realized by using standardized communication protocol. How this should be realized is left open in this study. Some kind of spatial query language or GeoSQL is needed, however.

Regarding the communication between the Geo database management system and the stereo workstation software, the need for image representation standards must be emphasized. We feel strongly that the digital imagery must be stored by using image compression methods like JPEG. In addition, a standardized method is needed for retrieving compressed images in tiled form Representation of the parameter information (like the orientation of an image) requires standardization as well (see Sarjakoski & Lammi, 1991 and Lammi & Sarjakoski, 1992).
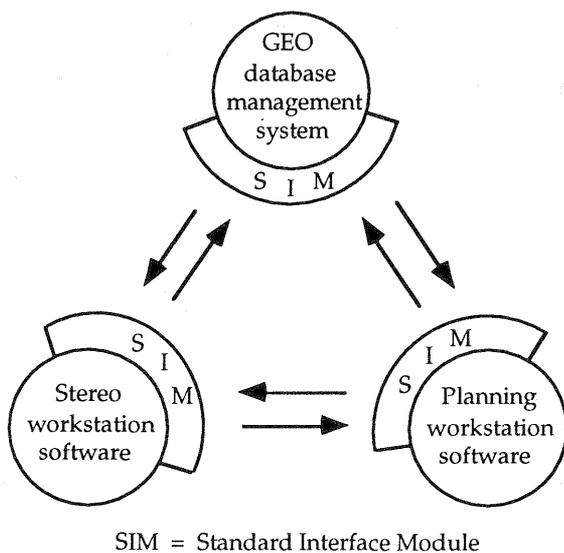

SIM = Standard Interface Module

Figure 2. The flow of data between the system components.

6. DESIGN ISSUES FOR USER INTERFACES

Introduction of menu- and mouse driven windowing systems for graphics workstations has been the most important innovation for easy-to-use user interfaces. Gradually all workstation vendors have accepted their use. However, the use of nice looking windows does not guarantee user-friendliness.

Design of good user interfaces for computing systems is a relatively new field for systematic scientific study. Its goal must be in understanding how to facilitate efficient human-computer interaction - the term efficient covers a broad spectrum of ergonomic, psychological, cognitive and other aspects.

Frank et al. (1992) have identified user interfaces to be one of the most important items for GIS research in the near future. In this section we want stress the need for systematic use of some methodologies in the design of user interface(s) for a stereo workstation. Two specific issues - user models and metaphors - are studied more closely.

6.1 User models

User model refers to a systematical implementation of the important features describing the user. The main interest in the user model research is in systems which can adapt themselves to different users at run time. The most important function of user models is to predict user's actions and preferences and change its functionality accordingly, for instance in database search. Rich(1983) has devised three dimensions for describing user models:

1) one model of single canonical user versus a collection of models for individual users,

2) models describing explicitly by the system designer or by the users themselves versus models inferred by the system on the basis of user's behavior,

3) models of fairly long-term user characteristics such as areas of interest or expertise versus models of relatively short-term user characteristics such as the problem the user is currently trying to solve.

Brajnik et al. (1990) list three advantages of using user models: the economy of interaction, user acceptability and effectiveness and efficiency of the use of the target system.

6.2 Metaphors

A metaphor is a "figure of speech in which a word or phrase denoting one kind of object or action is used in place of another to suggest a likeness or analogy between them" (Websters Third New International Dictionary). Recently metaphors have been referred a lot in studies related to the user interfaces. The desktop metaphor first popularized in Apple Macintosh uses concepts and terms like "document", "folder", and "put into a trashcan" instead of more conventional computer terms "file", "directory" and "delete a file". The power of the use of metaphors is based on the idea that novice users of the computer can use it as a helpful tool without need to study the computer terminology. Its functionality will be understood through analogy.
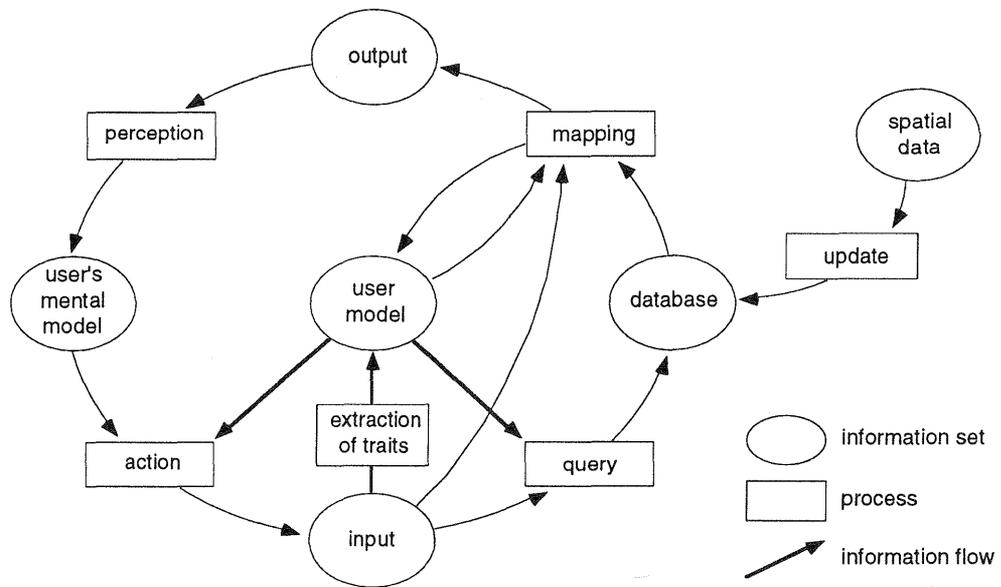
Figure 3. The position of a user model in GIS communication system (Lindholm & Sarjakoski, 1992).

6.3 User models and metaphors for stereo workstations

The hypothesis of this work is that a stereo workstation in GIS environment is used by the end-users of geographical data for various purposes. The user models must incorporate the most important characteristics of the tasks. These include at least

application areas:
- town planning
- landscape architecture
- building design
- road design
- utility planning
- traffic analysis
- forestry applications,
- map revision = update of geo database

professions and educations:
- architect
- civil engineer (construction, utilities, traffic,...)
- forestry expert
- surveyor.

The user models will affect at least following aspects
- language
- terminology
- functionality of the system
- availability of various tools
- graphical interface and menu layout
- extensions with application specific "power-tools".

Figure 3 illustrates the role of a user model in GIS communication system. Although its emphasis is on query systems, the same principle applies for stereo workstations, at least partly.

Our believe is that with today's knowledge and technology it would be over-ambitious to apply user modelling so that the model would be inferred during the session. It is rather suggested that a tailored interface is made for each user. This will make it possible to use all the useful application and user specific metaphors and peculiarities facilitating efficient and ergonomic use. This kind of approach makes it necessary that the workstation software is clearly modularized so that it consist of 1) a kernel software and 2) tools for the tailoring of the user interface. The tools, on the other hand, are a combination of some kind of macro language and an easy-to-use interface editor. Apple Macintosh HyperCard and its successors are a good example of appropriate tools. Who is then responsible for the tailoring process? Our believe is that often an "interface specialist" is needed for making the tailoring work. It is also likely that experienced users are willing to make some tailoring by themselves - as experienced users of text processing systems write their own macros.

A tailored user interface may also be regarded as a knowledge-based layer on the top of the system (Sarjakoski, 1988) in which the knowledge base contains the user model.

7. OUR EXPERIENCES

For the implementation of a stereo workstation at the Finnish Geodetic Institute, an Apple Macintosh IIfx microcomputer has been chosen. It has a Motorola 32 -bit microprocessor 68030 that runs with 40 MHz. RAM is extended to 32 MB. Three button mouse, Logitech MouseMan is used as a three-dimensional control device. The internal hard disk has the capacity of 160 MB. External hard disk (1 GB) is added to enable quick access for large image data often used, this disk is

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connected by using a SCSI link. An optomagnetic diskunit with cartridges of 600 MB is used to store the digital imagery. Compression/decompression is done by the Storm Technology's PicturePress software with Micron Xceed ICDP-II Picture Accelerator.

The display system consists of two monitors, one is used as a monomonitor (RasterOps/Sony 19" with RasterOps 24L 1024*768 24-bit full-color graphics card) while the other one is used in stereomode (Tektronix SGS625/ Sony 19" stereoscopic display system, with Radius PrecisionColor 24X 1152*882 24-bit full-color graphics card). The used stereoscopic display system is based on polarization technique with passive glasses.

Images used in our stereo workstation were digitized by the Sharp JX-600 scanner in full-color mode and resolution of 600 dpi. Stereopairs were formed in a preprocessing phase where images of the stereopair were rectified to a common rectification plane so that the requirements of the normal case of stereophotogrammetry are fulfilled. The same principle has also been used in other stereo workstation implementations as in Azizi (1991).

The stereo workstation at the Finnish Geodetic Institute is based on the fixed view, moving graphics -paradigm. It is designed to have several windows for a single stereomodel. One of these windows is totally reserved for stereoscopic viewing and it is placed alone on the stereoscopic display monitor.

Because used digital images are quite large they are handled in parts, i.e., displayed windows contain only a small part of the original image. When some other part is wanted to be displayed it has to be read from the mass storage. The selection of the viewed area is done by pointing the area of interest on the overview image. This overview image is a lower resolution version of the original (left) image.

The selected working area is displayed on the mono window (one for each image). These mono windows may be used whenever stereoscopic viewing is not needed. A pair of special zoom windows is provided for a closer look of images. These zoom images give also a possibility to do more accurate visual interpolation while editing. Image for stereoscopic viewing is produced from the prerectified mono images either by duplicating columns or leaving every other line from the images away. These images are shown on the stereomonitor left over the right.

Windows containing the displayed image data can be moved inside the monitors. This does not apply to the stereo window because it is strictly tied on the dimensions of the stereomonitor. Several images can be opened simultaneously inside the restriction of the RAM space (32 MB).

An ordinary three button mouse is considered as a 3D input device. All the steps produced by moving the mouse are handled as increments in the model space. Third dimension is achieved by reading the center and right mouse button presses as height increments. Model

space coordinates of the 3D point are changed to the ground coordinates and this point is projected to the left and right image.

8. SUMMARY AND CONCLUSIONS

In this work we have regarded a stereo workstation as an end-user tool or system for the utilization of stereo imagery and other data stored in GIS database. The idea of multipurpose workstation is emphasized. A stereo workstation is a functional extension of an ordinary graphics workstation. The necessary hardware extensions should be minimal. The cost of the workstation have to be so low that each user can have a workstation dedicated solely for him.

The workstation software should be designed to support interactive work as well as possible. The principles of many CAD and drawing programs should be followed. The fixed view - moving graphics is used in them exclusively. We argue that for the stereo workstation software it is not only the most economical but also the most ergonomic solution. Special attention should also be paid to sub-pixel accuracy and visually pleasant superimposition of graphics.

The issues of user interface design become important as the workstation is targeted for end-users outsize the mapping field because "for GIS users, the user interface *is* the system" (Frank et al., 1991). Sound methods should be developed for user interface design. We have proposed that the methods of user modelling should be studied and finally applied. Application and profession oriented metaphors could be used to make the system easy to adopt. Each user should be supplied with his/her own interface.

Strict modularity should be applied on all levels of the system. Geo-database management system must be a well defined entity or sub-system with a standardized interface for communication with the stereo workstation software and other related applications like a software for some planning purpose. The same or similar interface must be for immediate communication between the stereo workstation software and other application software. The stereo workstation software itself should be layered so that it consists of a kernel software and tools for complete tailoring of the user interface.

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