AN OBJECT-ORIENTED STEREO SYSTEM FOR 3D-MEASUREMENT

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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 with an according pricing 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 are shown. The key role of OpenGL^{TM} 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 some sample functions concerned with image display and handling are presented in more detail.

1 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. In the following, motivation and background for the proposed solution are outlined, the design of the system is sketched and some technical details are presented.

2 PHOTOGRAMMETRIC TOOLS

2.1 General

Since the end 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.

2.2 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.

2.3 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.

2.4 Close range aspects

In the past, close range applications have been distinguishable from topographic applications by size, appearance and shape of the objects and by the size of the images. The differences for the objects will remain for the future but the size of the image data will get closer. Camera sensors designed for close range use begin to have sizes of up to almost 30 million pixels with increasing tendency. It is for sure less than for aerial images but enough to produce considerable work load for the workstations.

On the other hand, there arise simplifications from the needs for the data capture functionality. In many cases the focus of the application is the field of CAD. Here the data collection is mostly restricted to 3D points, and no semantic information is needed. Furthermore, in this field several prominent software packages are existing (AutoCAD and other), which can be used for all necessary steps the user want to apply to the data it once has been collected. With

respect to a digital workstation this does give the opportunity to avoid development effort within the application field and allows to concentrate onto the photogrammetric aspects and the viewing and measuring features.

3   AUTOCAD INTERFACE

3.1   General

The most prominent candidate for an integration into a photogrammetric evaluation process is AutoCAD. It is the most widely used CAD Application today and comes from Autodesk Corporation. It's available for the most common platforms (DOS, UNIX^{TM}, Windows flavours) and various languages. One important reason why it's so popular is that it can be easily extended by the use of the programming languages AutoLISP, C and C++.

This gives a lot of different possibilities for an integration of AutoCAD with a photogrammetric data collection environment. A binding can simply be achieved by a data interchange process but an integration on the level of dynamic libraries is possible too. Even an object-oriented approach is provided using the interface based on C++, thus supporting modular concepts for the integration. The different strategies for an integration are represented by the available interfaces ADS and ARX.

3.2   AutoCAD interface languages

3.2.1   ADS. ADS (AutoCAD Development System) provides a C interface for the programming of AutoCAD functionality. It is a C converter used to transform control features into AutoLISP, a specialized dialect of the artificial intelligence language LISP. The ADS programs written in the C programming language are using the functional programming paradigm. It's possible to create reusable modules and develop smaller programs fast without spending too much time for design decisions. ADS programs are compiled executables and must go through the debug-compile-link cycle when changes are made.

3.2.2   ARX. In addition to the C interface ADS there's a C++ interface called ARX (AutoCAD Runtime eXtension) available. Using the C++ interface it's possible to take full advantage of object-oriented techniques like derivation and build specialized class hierarchies. The ARX interface already defines a set of classes to manipulate entities (visible objects in a drawing) and objects (entities and invisible objects in a drawing). ARX programs are typically compiled as a Dynamic Link Library (DLL) which is then loaded by AutoCAD when needed. Similar to ADS programs they must go through the debug-compile-link cycle when changed.

3.3   Possible strategies

The advantage of ADS programs is that they're completely independent from AutoCAD memory space. This means that even if the ADS program crashes it has no effect for the running AutoCAD application. ARX programs, however, share memory space with AutoCAD leading to the problem, that crashes within ARX affect the AutoCAD application too. In terms of robustness, therefore ADS has some advantages. With respect to speed, it is just opposite, the ARX interface allows to communicate directly with the AutoCAD database and is therefore faster than the ADS interface. In addition, ARX permits object-orientation and fits well to the design of the photogrammetric software components, giving some advantages in terms of development effort.

4   DESIGN OF THE PROPOSED SYSTEM

4.1   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 Microsoft^{TM} 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

(GUI) (Smart, 1999). This provides all necessary routines for the installation of graphic solutions within different environments and additionally gives the corresponding look and feel.

4.2 Hardware

Central part of the hardware is a Intel® 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^{TM}-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-measurement 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.
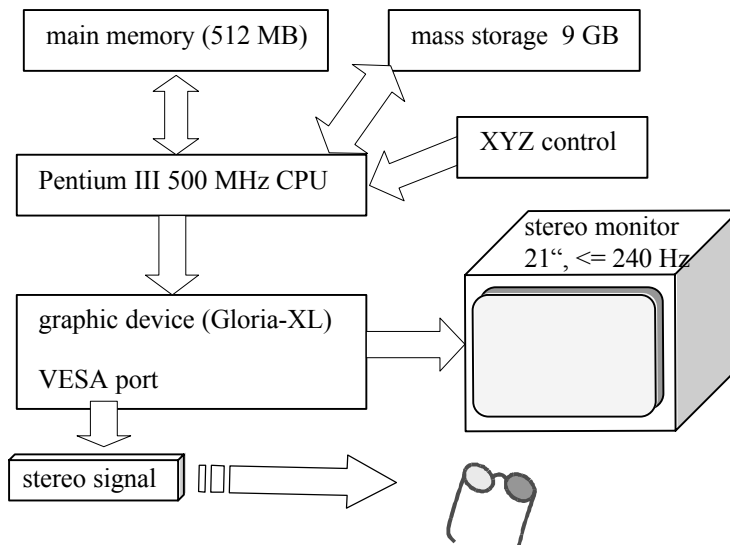

Figure 1: system components

Of principal 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.

4.3 Software

4.3.1 Design. The software (cf. Fig. 2) has to fulfil all functional needs, but has additionally to consider requirements coming from the wish to avoid hardware dependence, to be flexible to the technological progress, to be able to exchange components and to incorporate new ones and to reduce the effort for maintenance. There is only one way to support all these wishes, that is to use an object-oriented programming approach. With the final design in mind this moreover allows to
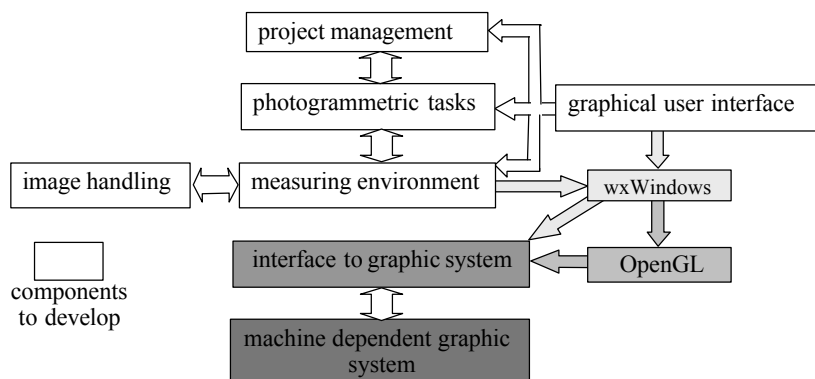

Figure 2: structure of software

realize the system step by step, starting with a simple prototype which will be extended as more elements are available. Selected language is C++, because of it's popular character permitting to incorporate existing solutions, which are widely available.

One very important already existing component is the graphical user interface wxWindows. It is an object-oriented software solution written in C++, which is useful for generation of graphical elements and has the advantage to provide all necessary libraries needed to transfer a solution to the graphic environment given (Windows, Motif, etc.). Choosing wxWindows allows to make use of three important features: object orientation, system independence and integration of existing resources.

4.3.2 Photogrammetry. Photogrammetric tasks have to take care of the metric aspects within the framework of this solution. Three fields can be identified with important photogrammetric contributions:

- preparation of the stereo model

- geometric calculations during evaluation

- user support during evaluation

Furthermore some components within the measuring environment are affected by 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, what 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.

4.3.3 Graphic. As shown in Fig. 2 almost all components have a relation to graphics. Simple ones are those providing the user with appropriate tools to introduce data, to control the course of work or to be informed about results, actual process stages or any events.

The more demanding elements can be found in the context of the measuring process. Here, graphic means handling of large amounts of image data either in the context of displaying information within a viewer or with respect to manage buffers of image information, which have to keep track of the progress of activities applied to the image data. Fortunately a lot of functions are available from OpenGL, relieving from the need to deal with elementary graphic functions. In addition, the possible hardware support may accelerate activities considerably.

Just to mention some of the photogrammetry related graphic tasks it should be noticed that there different display modes necessary:

- single image and double image within preparation steps

- stereoscopic mode for 3D-evaluation

- combined display of image information and evaluation results for control and visualization purposes

All image related display modes need to have appropriate support to move through the image, to improve the display characteristics and to control the image zoom.

5 IMPORTANT FEATURES

5.1 Portability

Portability means for this application to allow installations on various platforms. Although the primary objective is to use a standard PC environment, other configurations may be useful for graphic applications as well and it therefore should be possible to additionally amortise the development by installations on other systems (LINUX, UNIX, MAC, OS/2, ...). Trying this one primarily has to handle hardware and system dependent differences. In the context of this solution this is mainly the graphics environment. Even the use of some standard graphics software components like OpenGL doesn't prevent, that there remain discrepancies in the control of graphic devices (UNIX: X11, PC: WIN32). The problem might be simplified by an object-oriented design of the software, allowing to separate between system and application dependent components. But even then one needs to have the appropriate control functions for the graphic devices. In this context it is extremely helpful to have software tools bringing in the device dependent components, which only have to be exchanged if a system change is intended. Exactly this performance is introduced by the wxWindows GUI.

This framework provides an easy-to-use set of classes to develop platform independent applications in C++. It is used by a wide variety of users in commercial, education and research. It uses the native controls whenever possible. Controls not available are emulated such as tree controls under UNIX. Another main goal is that you get the full source

which makes quick bug fixing possible. It's design is close to that of the Microsoft Foundation Classes (MFC) and the event handling mechanism using event tables is equal.

5.1.1 Classes in wxWindows. It has all GUI classes needed to build a modern ergonomic user interface. For example classes for frames, controls, toolbars and menus are included. But wxWindows does not only provide GUI classes. Various helpful classes are available for handling configuration files, display a OpenGL canvas and printing preview to name only a few. To save a program configuration the native methods are used. That is the registry under Windows and plain text files under UNIX. These capabilities are useful for handling project files too.
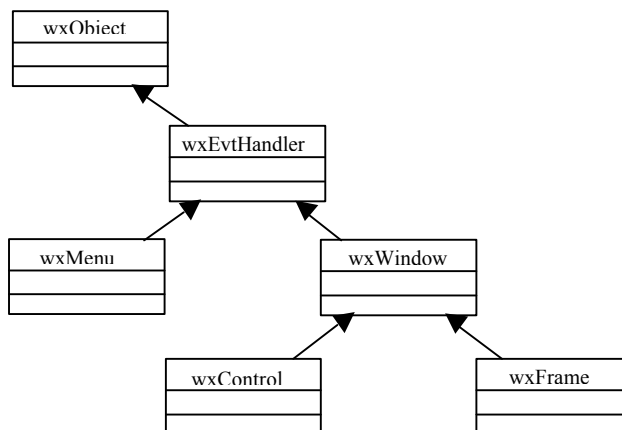
Figure 3: Simple UML showing some wxWindows classes

5.2 Use of OpenGL

OpenGL serves as the underlying graphic system for the proposed application. It handles all graphic output and the main image processing. We take full advantage of the functionality OpenGL provides but currently don't have to use all features. It supplies much more then just the low level pixel operations we're using here. For example texturing, lighting, fog, antialiasing and clipping are interesting features that can be used when modeling 3D virtual worlds. Some of this advanced features might be of interest in the context of visualisation within later versions. The high performance of OpenGL and the application using it is founded on the use of state variables controlling the visualisation. Therefore OpenGL is often referred to as a state machine. One doesn't need to set options every time a function call is performed.

5.3 Handling of large data sets

This is one of the most important features, because of the possible size of the images and the fact, that a photogrammetric operator expects to have a fix floating mark and a continuously moving image. In cases of analog instruments this does not produce any major problem, but in digital systems this requires an effective handling of large data quantities.

The amount of data prohibits to think about a complete storage of the image data within the video buffer and even the main memory is much to small to take all of the image information. Consequently the mass storage is the space where to keep the data during measurement. However, the transfer speed of mass storage is in-acceptable for a dynamic viewing process. It therefore has be designed a three stage solution to combine capacity with reasonable access rates (cf. Fig. 4).
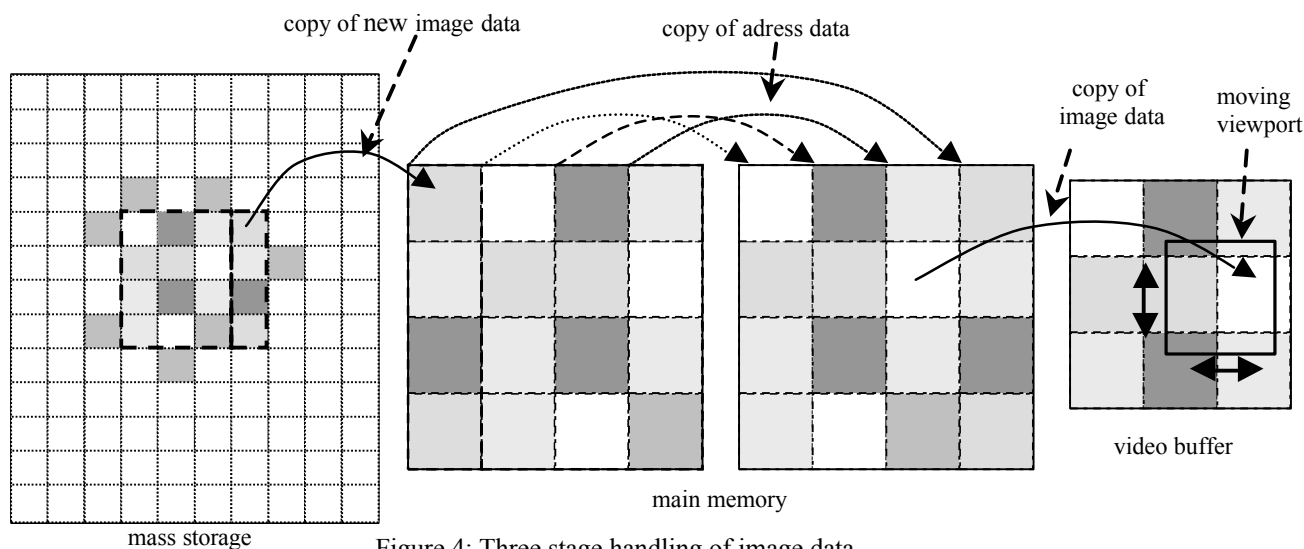
Figure 4: Three stage handling of image data

To achieve speed and flexibility, the image is separated into tiles, which will dynamically be copied into appropriate memory locations. The content of this memory covers the actually needed image fragment and some additional buffer

space. The memory is partly reloaded as soon as new information in the border region is required. The topology of the memory then doesn't correspond to the image data. It is reconstructed using a second memory serving as base for the video buffer. In order to avoid unnecessary image transfer, the content of the second memory space is created simple by copying addresses. Finally the video memory gets it's data from the second buffer.

This concept allows to keep most of the image data in the mass storage and restricts the data transfer to the inevitable minimum.

5.4 AutoCAD Integration

To make the described 3D-measurement accessible within AutoCAD, the full functionality of the proposed system must be integrated into the AutoCAD application. For ergonomically reasons this integration should be as seamless as possible. The most simple way for an integration is to use the photogrammetric environment as a coordinate collection tool. It then will be activated by AutoCAD, when the user wants to construct any desired geometric element, like points, lines, or arcs, for example. This allows to handle the complete evaluation process under control of AutoCAD and assures the access to the complete functionality provided by the CAD system.

However it has to be considered, that the graphic interfaces of AutoCAD and photogrammetry are in competition to each other. Thus it is necessary to display them alternatively in order to have enough display space for each application. Consequently the data flow has to be possible in direction from AutoCAD to the measuring tool too, in order to display the already captured CAD data within the images permitting to support the operator with the information needed for an effectively working measuring process.

6 SOLUTION DETAILS

The OpenGL Application Programming Interface (API) provides some very helpful functionality to implement viewing techniques. Because today's graphics cards often have build-in OpenGL support and there are some graphic cards with hardware acceleration available it makes sense to use this API for such a kind of application like we're doing here.

6.1 Image pan

With OpenGL it's possible to display bitmaps or images by using the OpenGL API function glDrawPixels(). Therefore this function plays a major role for image pan. It uses raw pixel data as input and writes this to a specified position in the OpenGL virtual universe. The idea behind is first to display the image at a given position and if the user wants to move the image, the position has to be updated and the image will be displayed at the new position again. To display an image it would be enough to have one buffer. But in cases of animation like the image pan here one needs to have two buffers. OpenGL calls them front and back buffer.

Figure 5: Various raster position scenarios (Kilgard, 1999)

Figure 5 shows some various raster position scenarios. A: raster position is within the view frustum and the image is totally within the viewport. B: raster position is within the view frustum but the image is only partially within the viewport; still fragments are generated outside the viewport. C: raster position is invalid (due to being placed outside the view frustum); no pixels are displayed.
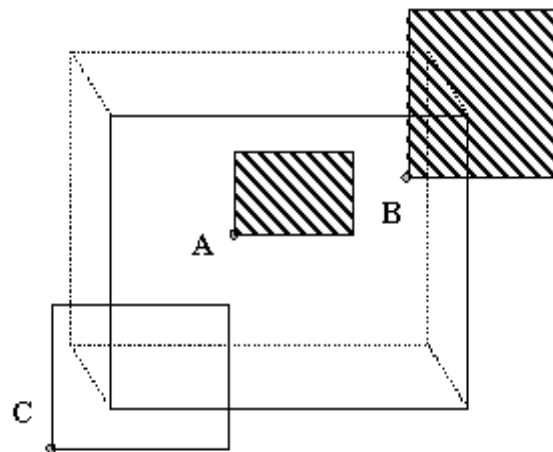
To avoid the invalid raster positions the following technique could be used: First setup the raster position to the origin with a call to glRasterPos*(). Secondly display an zero-width and zero-height bitmap at the current raster position with a call to glBitmap(). Within this call it's possible to set an offset with relative coordinates for the new raster position. This new raster position may now lay outside the view frustum but an image drawn at this position will render completely (Kilgard, 1999).

6.2 Image zoom

The zoom functionality is implemented using the OpenGL API function glPixelZoom(). If images are displayed using glDrawPixel() one pixel of the given pixel data corresponds to one pixel on the screen. The glPixelZoom() function now

specifys a factor for the x and y direction to change this correspondence between data pixels and screen pixels. For example one may specify a factor of 2 for both directions: Now one data pixel is drawn using four pixels on the screen.

With this API function call it's possible to avoid calculating pyramid layers of different zoom states increasing the amount of data necessary to display the image.

6.3 Stereoscopic display

Because OpenGL already comes with build-in stereo support it's relative straightforward to use this in an application. In chapter 'Image Pan' the front and back buffer of OpenGL are mentioned. In addition to these usually two buffers in stereo mode are four buffers needed. Front buffer left and right and back buffer left and right. To use this buffer constellation one has to request a pixel display format that supports stereo buffers. Not every pixel display format supports this four buffers. It depends on the graphics card memory and graphics card driver on what resolutions and refresh rates one is able to request stereo buffers in an application (cf. Fig.6). Another aspect is to take care of the offset between the two images that creates the stereo effect.
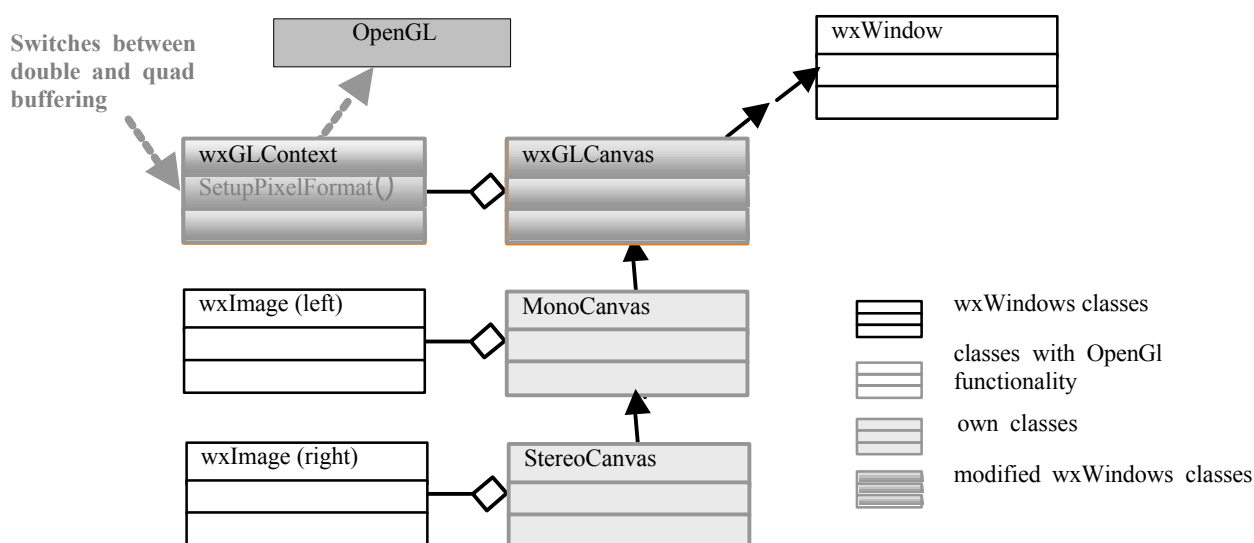
Figure 6: UML diagram for construction of a stereo window object

7   CONCLUSION

A conception based on standard computer hardware and software components has been presented allowing to develop a digital photogrammetric stereo workstation meeting all requirements for effectively performing 3D-measurements. The use of standards permits to use hardware acceleration and thus provides the speed necessary, to incorporate most graphic functionality necessary for user dialogs and image viewing processes, what allows to considerably reduce the effort of development. Furthermore, the incorporation of software handling digital object points, like AutoCAD for example, gives the ability to use the evaluation functionality being available there.

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