A PC-based stereo system for the collection of 3D-data for as-built documentation

Frank Boochs, Stephan Eckhardt, Ben Fischer

i3mainz, Institute for Spatial Information and Surveying Technology
FH Mainz, University of Applied Sciences

Holzstrasse 36, D-55116 Mainz, Germany

boochs@geoinform.fh-mainz.de

Resumen / Abstract

A precise and true geometrical description of built objects is a fundamental base of most applications and is a must in the field of CAD. Such a geometry is in general expressed by a large number of individual points placed on the geo-object in consideration. The total quantity of these object points is called digital object model and is generated by a data collection process. Several different techniques are known for the collection of points and a very common one is the use of metric stereo images. Then special equipment like stereo plotters have to be used. The technology of such instruments has been developed permanently and has led to very productive and flexible computer assisted plotting systems. Recently, the big technological step to pure digital systems has been undertaken. However, the need of having the image information digitally available is a very demanding constraint for digital plotting systems. In many geo-applications images with a size of 23 by 23 cm^2 have to be used, what results in very huge data sets. Therefore most digital plotting systems have special hard- and software components for the handling and display of such large images.

The lack of these systems is, that they are very expensive and that their software depends on the hardware used. This hardware is very special, why the customer may not use his own one and the producer additionally has to invest great effort to keep track with his software to the progress in hardware technology.

In parallel a great technological progress can be observed in the field of 3D applications, which is driven by the market of 3D animated and graphic oriented computer games. This market is dominated by PC systems, which are well equipped giving the power needed for multimedia applications. Looking at the potential of these PC-systems it is of interest to have the possibility to use them for stereo measuring process. This can be achieved with software designed under the aspects of photogrammetry but without any constraints coming from an adoption to special hardware features. This guarantees portability and the advantage to use the software on different platforms. With respect to as-built applications this software needs to integrate components allowing to easily extract typical geometrical elements of facilities. This integration is more than using simple CAD construction tools. It needs to incorporate the construction into the virtual stereo model in order to provide a powerful tool for the data collection.

A solution for that task can be found, when object oriented software packages from photogrammetry and CAD are combined. We have done this, by integration of the OPENCascade CAD package with our own photogrammetry software developed and designed for the use on standard PC systems. The design of soft- and hardware and the integration of the CAD package will be presented and first results with the prototype will be shown.

Introduction

Digital images are increasingly playing an important role in the photogrammetric business and have certain advantages in the context of the geometrical documentation of man made objects. 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 number of images existing in a project and their size makes it necessary to have an intelligent solution for the data handling and a powerful computer equipment allowing to effectively display the images during the different interactive evaluation steps. 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. In addition, open and modular software is not only available for photogrammetric purposes, but can be found in various disciplines. For example, within the fields of design and lay out of geometries manifold CAD packages are obtainable. The use of such packages and their integration into own solution reduces the total charges for the development and simplifies the design and presentation of new tools.

Based on the aspects of simplicity, modularity and flexibility a software solution (DISTA = digital stereoscopic evaluation architecture) has been designed and will be extended for as-built applications. 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.

As-built documentation

General aspects
The documentation of man made objects is of interest in many fields of application. Typical use can be found in

- Industry
- Archaeology
- Forensic tasks
- Planning
- Civil engineering

for example. This list can be extended easily.

Figure 1: Part of an industrial Plant (curtesy MENSI Corp. 2002)

The documentation is of value in all those cases, when a digital object model is necessary but not available. Up to now only few existing objects have their own digital data sets expressing geometry and perhaps appearance. The majority of the actually existing man made objects have been built without developing CAD data sets a priori. Furthermore, if a prior CAD geometry served as base for the construction, this data might not express the real object as it deviates from the planned one during the process of construction. From this originates the need for a documentation, when a true digital model is necessary for some reasons.

With respect to industrial plants, for example, the need for a geometrical documentation arises from many reasons having to be seen in the context of a secure and efficient function of the whole system:

- Capture of the actual plant geometry for the first time
- Capture of some parts in context of devised modifications
- Capture of the newly built parts
- Capture of the actual plant geometry in context of security aspects

- Capture of the actual plant geometry as base new planning
- Capture of the potential deformations caused by their function

Although planning and design of new components is nowadays done by means of tools based on information technology, most real plants exist without actual and useful data of their geometry. From this, a straight forward use of IT for plant managing is blocked, compatibility problems are arising, because the geometrical reality of old components doesn't fit with the newly planned ones and the costs are increased, whereas the efficiency will be decreased.

This problem only can be avoided, when existing objects are geometrically documented and/or evaluated. In particular, this needs an adopted procedure allowing to collect the data in question. Preferably this procedure should be easy to use, flexible and effective. The following features then have to be considered:

- Shortest possible stop of production processes during data capture at the object
- Acceptable costs
- Sufficient accuracy

In order to limit cost elements some further aspects have to be kept in mind:

- minimal effort for the preparation of actions at the object
- minimal effort for the preparation of evaluation tasks
- acceptable manual effort
- shortest possible time for data capture

Most of the existing tools for documentation purposes don't match with the demands sketched. Especially the amount of activities at the object itself is often too high. As result, the cost are higher than acceptable, as the interruption of the process of production is long. This might end up either in an investment higher than necessary, in a simplification of the object allowing for a reduction of the effort or in dropping the complete data capture. We therefore would propose an image based 3D-technology, because it avoids many of the problems mentioned and provides best preconditions for an adequate data capture.

Image based data capture

Images are ideal from several points of view:

- they allow minimal activities within plants
- they permit to store very high density of information
- they are selective with respect to extraction of geometrical elements
- they provide geometrical and textural data
- they are flexible to use and can be captured anywhere in or at an object
- captured in a digital camera system, they directly allow to enter a digital processing chain
- they provide the potential for an manual and interactive data collection and in parallel for computer based activities

With respect to costs an image based procedure has advantages too. Apart from the shortest possible interruption of production processes the equipment is affordable. This holds as long as one uses conventional high resolution digital camera systems and avoids to use specialized hardware for the process of evaluation. The later one is not very common up to now, but by use of PC-based solutions as we propose this might be achieved.

In principle, for an image based data capture one has to distinguish different steps:

At the object:

- establishment of a geometric reference
- if desired, preparation of the object with signals useable for an automatic detection process
- selection of exposure positions
- image capture

at the laboratory:

- orientation of all images
  - manual or computer based detection of tie points
  - calculation of orientation values
- generation of stereo images
- if desired, establishment of an image archive, facilitating the access to individual images
- 3D-evaluation of stereo images
  - interactive selection geometry model for object parts
  - measurement of necessary key points
  - determination of geometry for the object part

This processing is characterized by following aspects:

- most work load is put into the laboratory
- the generation of the object parts is founded on the visual 3D-inspection by the user
- supplemental measurements are easily possible
- the object will be documented visually
- the parts to be collected must not be accessible
- a careful and sufficient selection of exposure positions has to be assured

In addition, the whole process is very selective as the evaluation can be restricted to those components necessary and has not necessarily to be extended to the whole content of the images. This allows to act very flexible, because the images are documenting the whole objects but the evaluation concentrates on these parts which have to be collected. The visual information allows to collect other parts in the future, when they are needed.

However, the process of evaluation might be a time consuming one. This happens, when the images are not evaluated using stereoscopy. Then, each image is used individually and the user has to compare each object point with its projections into other images. Doing this, he avoids wrong selections coming from different perceptions of a point in different images. Hence the effort for the measurement increases although the quality is inferior to a stereoscopic measurement. Using stereoscopy, object points will be selected more secure especially when the object is not prepared by special targets. We therefore prefer to use stereoscopy as perception process for an effective and accurate measurement system.

Conception of the 3D-system

General aspects

An image based 3D system for documentation and evaluation has to fulfil different aspects:

- adopted functionality
  - treatment of numerous images
  - collection of orientation points
  - calculation of orientation parameters
  - generation of stereo images
  - collection of objects based on CAD technique
- affordable
- powerful
  - unlimited number of images
  - unlimited size of images
  - fast
  - accurate

Functionality and capacity are mainly determined by the design and components of the software, whereas speed and affordability are mainly fixed by the equipment.

In order to assure high speed and capacity several manufacturers offer special digital workstations. They are generally based on powerful graphic workstations equipped with special viewer components needed for the stereoscopic perception process. Moreover the software solutions are often adopted 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 manufacturer
- low flexibility to technological changes

Most of these items are caused by the proprietary characteristics 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.

It seems promising to avoid proprietary solutions. 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 use available standards as far as possible and insert open resources in order to reduce the development effort.

System design

Concluding from the deficiencies of specialized solutions we use a modular concept based on available standards and corresponding resources (cf. Fig. 2). With respect to the display of images and handling of graphic data, for example, we use the most common standard: OpenGL /5/. 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.

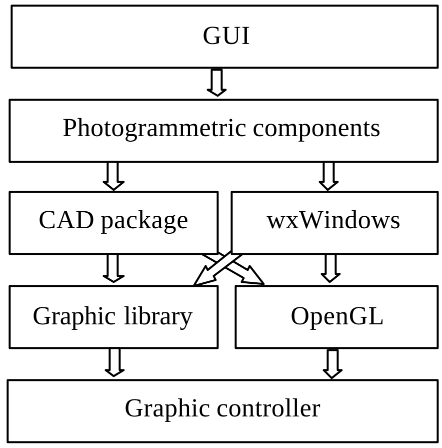

Figure 2: software components

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 there exist developments from other sides handling the problem of graphic interfaces in different computer environments. One very powerful solution is the wxWindows Graphical User Interface/7/. 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 /7,9/.

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, 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.

Finally, the use of OPENCascade offers the opportunity to add the complete CAD functionality especially needed for as-built applications. Most components of OPENCascade are open source and therefore available for free. This software has an object oriented structure, correspondingly providing modules (cf. Fig. 3) simply allowing to integrate the components necessary into the whole software package.

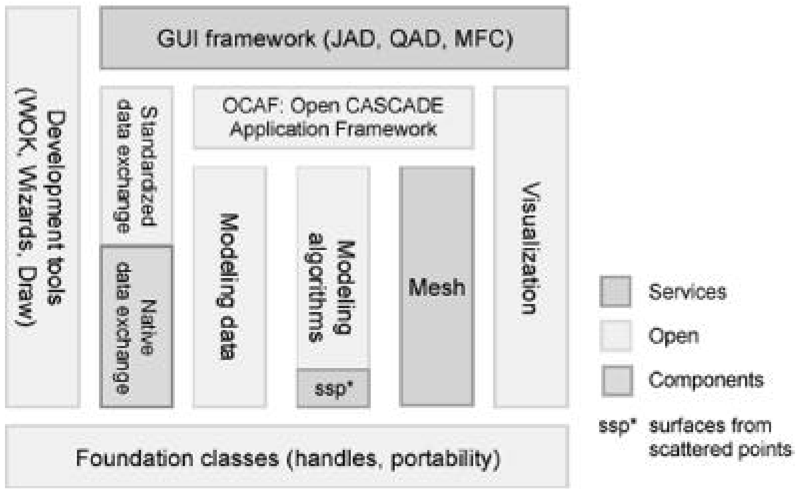

Figure 3: modular structure of OPENCascade

Functionality of the 3D-system

Preparatory steps

The first important step has to provide the possibility to get the orientation of all images. It is an essential precondition for further evaluation processes and has to be integrated in any photogrammetric software package. However, in the context of as-built applications one special aspect has to be kept in mind: all objects are three dimensional and for an as-built documentation they have to be completely documented in all dimensions of space. In order to achieve this, images have to be distributed all around the object providing all necessary sights (cf. Fig.4).

By means of orientation all these images will be transformed into a common space. As information a certain number of tie points has to be used, which have to measured in the images. When such tie points are prepared in the object by special targets the solution is simplified and might even be automated by means of image analysis. However, the use of tie points increases the effort at the object and is in contradiction with the aim of a minimal stay there.

Alternatively natural tie points have to be used. This doesn't produce a general problem, but might reduce the quality of the image measurements. Responsible for that is the definition of such points, which is inferior to the signals. Furthermore they have different appearances which are changing proportional to the variation of exposure positions and sights onto the object. Then it is of importance to have tools allowing to inspect the object points as they appear in different images. For the software this needs to provide the possibility to measure in parallel all these images having common objects parts. Such, the user might assure, that the tie points selected appear in all images as good as necessary and permit to collect as much data as needed to establish a stable geometry.

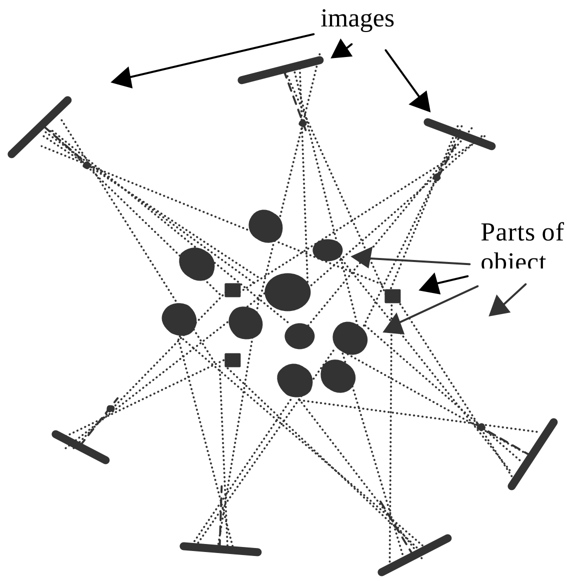

Figure 4: possible distribution of images within object space

Figure 5: User interface for the measurement of tie points

The software therefore has to administrate the data collection process in a highly flexible way. Instead of using one image at a time, a certain number of images need to be treated in parallel. The user must have the possibility to jump through all images selected in order to verify the selection of points and their measurements.

Within our software this is done by an appropriate window technique. There exist two windows for the collection of the measurements and an unlimited number of overview windows with all these images being selected (cf. Fig. 5).

After the orientation parameters have been calculated a final preparatorily step has to be performed providing the base for a stereoscopic evaluation. This is the generation of adequate epipolar images (cf. Fig. 6).

In general, images will be taken from very different perspectives, why no a priori stereo data will be available. However, with the orientation parameters any pair of images showing a common object part might be combined to form a stereo pair. A simple

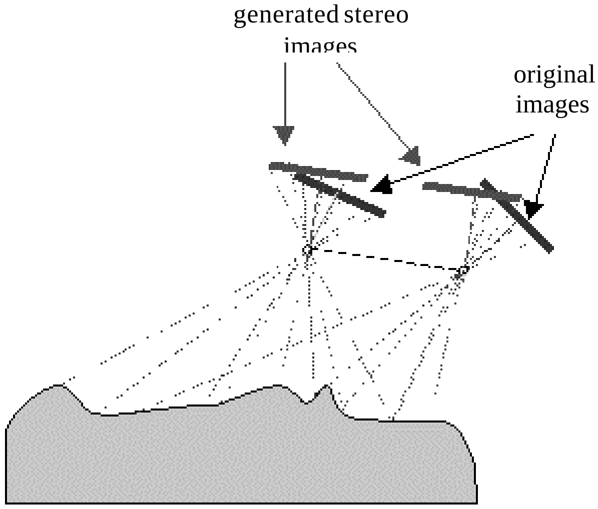

Figure 6: Generation of stereo images

rectification step assures stereoscopic perception for the user. Just enough overlap has to be there, in order to minimize organizational effort.

3D evaluation

Stereo on a standard PC

The process of 3D evaluation is the most demanding step for the system. One reason has to be seen in the necessity to provide a stereo environment. This results in a corresponding load for the hardware. A second aspect comes from the requirements for an efficient software tool allowing to work in large stereo data sets along with a appropriate user environment for the collection of CAD data.

The first problem is solved based on standard PC technique together with the standard graphics interface of OpenGL. Nowadays a PC simply can be equipped with graphics cards being developed and designed for the game sector permitting to view in 3D. These cards are powerful and affordable. Access to the graphics controller will be provided by OpenGL. It 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 the functionality to display images is encapsulated in those tools managing the view of images for the orientation processes it's relative straightforward to use the object oriented software structure to extend this class to handle stereo images. However there're some aspects having to be considered, 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 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 one has to render the content twice. Once for the left image and once for the right image

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.

CAD environment

The solution for an useful environment for data collection is founded on the integration of the free CAD software package of OPENCascade (cf. Fig. 7). This software is primarily used for the design and modeling of new objects. However it has interfaces (cf. Fig.2) providing access to all basic functions. It therefore allows to integrate the all tools for the generation of 3-dimensional physical objects into other object oriented software packages.

Figure 7: Part generated with standard tools of OPENCascade

The integration can be achieved combining the tools of object generation with the visual perception process within a stereo model. This has to be complemented by a substitution of the arbitrarily selection of points with the measurement within the stereo model. The resulting functional scheme is shown in Fig.8.

In principle the CAD environment provides all necessary tools for the extraction of objects from the virtual 3D model. Some modifications or extensions are inevitable, however the development effort is negligible compared to a complete new generation of all collection functions. Moreover, the user has its data directly stored in a CAD environment giving the opportunity to continue with other activities like simulation, artificial visualization or constructive extensions. Of special value is the fact, that for the open parts of the software the whole source code is available, giving all flexibility for modifications and adoptions of the CAD software as necessary to meet requirements arising from the use of stereo images.

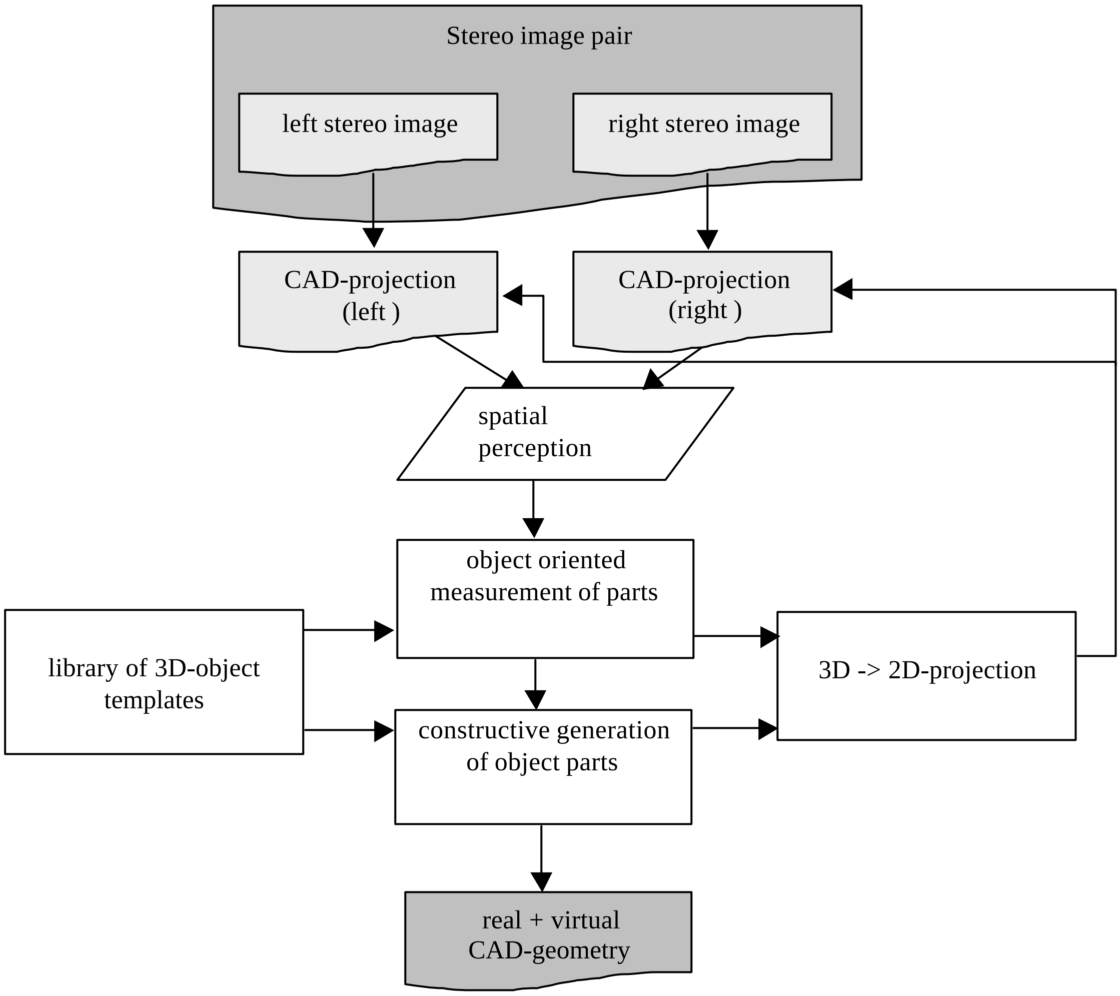

Figure 8: scheme of integration

Just to give an example, the following list names the classes of algorithms available for the modeling of any data used in the context of the generation of objects:

- Geometric Tools
- Topological Tools
- Construction of Primitives
- Boolean Operations
- Fillets and Chamfers
- Offsets and Drafts
- Features
- Hidden Line Removal
- Sewing
- Surfaces from Scattered Points

As can be seen, there exists an extensive set of tools useful for any purpose of modeling, constructing, combining and displaying physical objects of any shape, thus allowing to collect all the data originating from man made objects, regardless of their origin or type.

Conclusion

A modular conception based on different standards and software packages has been presented allowing to handle digital photogrammetric image blocks, to produce stereoscopic image pairs, to compile them performing 3D-measurements in the virtual 3D space spanned by these models and to extract data needed for as-built documentation. The use of the OpenGL standard permits to use hardware acceleration providing high processing speed even with standard PC equipment. Furthermore, standardization allows to incorporate from third party most of the graphic and CAD functionality necessary for data collection, considerably reducing the effort of development. An intelligent image handling permits to handle numerous and large images as they conventionally can only 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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