3D RECONSTRUCTION AND VISUALIZATION IN CULTURAL HERITAGE

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ABSTRACT:

This paper presents a modular software and hardware independent system for the 3D reconstruction in the area of culture heritage. This system can be used for the digitalization of 3D cultural objects, monuments and sites. The clouds of 2D or 3D scanned points (matrix oriented or scattered) even the 3D wireframe model are acquired by photogrammetric techniques (for example digital cameras or laser scanners) using different digitizing strategies in various topics of culture heritage. This input can be processed using an efficient algorithm for the reconstruction of the digitized object. If the digitalization delivers a complete set of scanned 2D or 3D data from all sides of the object, then the volume or so-called solid structure can be calculated. In addition to this, using special objects such as mummies, jewels or in general metal or ceramic artefacts that have interior structures (holes), the internal geometry can also be measured through the use of X-ray scanners and in this way the complete 3D reconstruction of the object can be achieved. Furthermore the developed system can generate the exchange of the processed data with other systems (CAD/CAM, e-libraries, e-museums) into 3D data sets in standard data exchange formats (IGES, STEP, VDAFS) as well as to VRML format for the visualization by a standard browser on the web. A variety of visualization techniques can be used for different multimedia and virtual reality applications. A case study of using this system in the area of culture heritage under a virtual reality environment will be discussed and demonstrated.

1. INTRODUCTION

1.1 Review

The 3D reconstruction, visualization and animation in the area of culture heritage comprise an issue that has engaged the scientific community for the last few years. The cooperation between different disciplines such as Photogrammetry and Computer Science (Computer Graphics) provided the opportunity to develop new tools and techniques, useful for the documentation and archiving of cultural heritage. Recently significant work has been done in the area of scanning and reconstructing the past in 3D format (Boehler and Patias, 2002).

The paper is a contribution to these efforts and thus it discusses a newly developed software functionality which receives as input digitized data (images, 2D, 3D points and contours). This data is processed and the end result is presented in the form of volume, solid oriented structures. Furthermore, the output can be directly used through standard interfaces by the majority of visualizing systems, CAD and FEM. In addition to this the software functionality can produce data sets not only directly for the reproduction of the object using milling machines or methods from the latest Rapid Prototyping technology, but also for animation and virtual reality systems.

A case study of using this system in the area of culture heritage documentation and depiction under a virtual reality environment will be discussed and demonstrated.

1.2 Digital documentation for cultural heritage

In cultural heritage a lot of work has been done in the last decades. Through international organizations such as ISPRS, CIPA and ICOMOS, the documentation and conservation of monuments and sites in 3D form has begun. On the one hand, more and more companies are developing more efficient, flexible and accurate digitizers (cameras, lasers, mechanical scanners). On the other hand, Information Technology (IT) is developing intelligent software for the further processing of large amounts of scanned data. This enables the scientist to use this data in CAD systems and in some cases directly in the production line for restoration purposes and/or the production of replicas.

However, these new developments lead to the problem of compatibility and standardization. Due to the great number of scanners available today and the different software accessible to the public the machinery and software often do not work together efficiently. This is exactly why there is a need today to provide standardization in the fields of cultural heritage and IT.

A universal and unique solution will be presented from digitization to reproduction in order to overcome the difficulties now facing the documentation of cultural heritage in 3D form.

2. PHOTOGRAMMETRY

2.1 Data collection

Digital Photogrammetry is a measurement technology that can be used for the extraction of 3D points from digital images. Thus, Photogrammetry derives all the appropriate measurements from the images, rather than measuring the object directly. That is why this technology provides significant advantages over the conventional surveying methods. Very often Photogrammetry is used in order to map and document cultural heritage objects like monuments, sites and artefacts.

Starting from the requisite image orientations (interior, relative and exterior), Photogrammetry can provide automatic process through image matching techniques for the collection of 3D object points. Initially, a cloud of interest points is extracted from the images. For the acquisition of interest points, the key point detector Plessey-Grid (Stylianidis, 2003) was used. One step forward, using cross-correlation or least-squares matching techniques the extraction of the cloud of 3D points can be achieved.

2.2 3D Model

Single 3D points cannot provide a global illustration about the structure of the object. Thereby, the creation of the 3D object model is a requirement in order to depict the formation and the real conditions of the object.

Furthermore, the 3D reconstruction is a requirement for further processes such as the application of visualization and graphics techniques which are explained in the following sections. In any case the 3D object model can be developed under standard or special CAD software.

The case study that is presented concerns an ancient tomb, while in Fig. 1 the extracted 3D model of the tomb is illustrated.

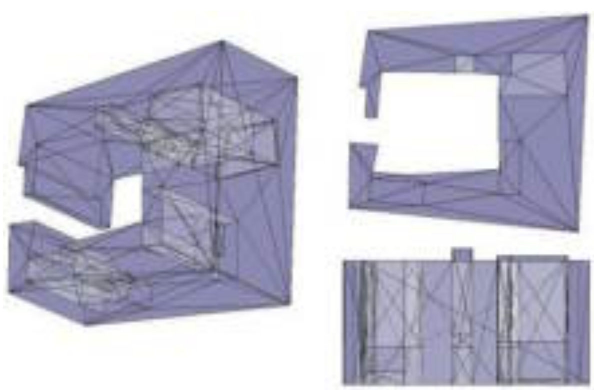

Figure 1. The 3D model of the tomb

3. 3D RECONSTRUCTION

3.1 Object Reconstruction in Three-Dimensions

The presented example makes clear that one of the results of Photogrammetry is the generation of point clouds with a large amount of data which cannot be processed by standard CAD programs. This section addresses the problems of processing the data so that they can be input into CAD software packages and of generating NC-programs for re-production in archaeology. Solutions for merging effectively independent laser scanner images into one common coordinate system will be presented.

3.2 Procedures for Merging Images

Several independent images must be merged when the object is larger than the field of view of the digitizer (camera) or the object exhibits undercuts. A very straightforward solution is using identical points in the overlapping area of neighboring images. This requires that these points appear with high contrast. In cases where identical points cannot be identified on the object itself, so called reference spheres can be applied (Wehr, 2001). Using these aids very precise results can be yielded.

The Cartesian coordinates that are the result of the digitizing of freeform objects by the camera are transformed into object coordinates by special software postprocessor. The coordinates may now be processed as either NC-commands for copymilling (duplicating milling) or rapid prototyping machines or in the data format for the sculptured surface modeller.

3.3 Post processing of Object Coordinates for Reproduction

A special software functionality is developed for the calculation and determination of loop contours out of one digitised dataset or out of the whole digitized object. In absence of a digitized statue this process is clearly seen in the example of the shop display mannequin (Figure 1 to Figure 5) and can be achieved in a two-fold process:
First set the boundaries for the starting and the ending levels of the calculation. Secondly, the user has the choice to calculate the contours in iso-distance or according to the curvature (the first and second deviation) of the object.

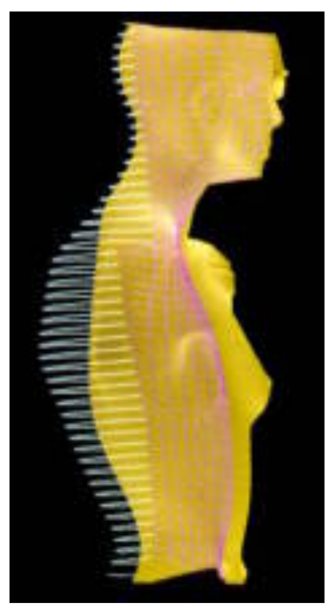

Figure 2. The calculated contours and freeform surfaces of a mannequin

The calculated contours can be interpolated in order to achieve smooth closed curves. This is possible due to the direct transfer of these data sets to two and half axes milling machines.

On the basis of these contours the triangulation and reconstruction process (Ioannides) can begin. The triangulation and reconstruction can be achieved using the Voronoi and Delonoy methods in 2D form at the beginning and later in 3D form (Delaunauy B. and G.F. Voronoi).

The calculated contours procedure will be the volume oriented model as well as the tetraeder form. Furthermore in specific cases, free form surfaces can be calculated and presented in standard data interchange formats.

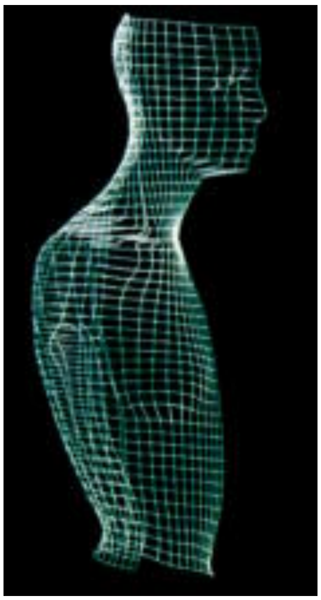

Figure 3. Half of the model as a Freeform data structure

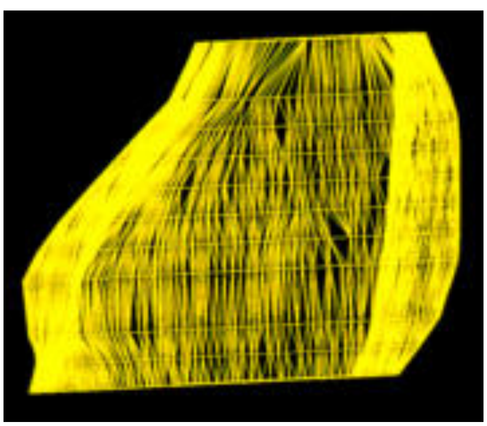

Figure 4. The triangulated structure of a part of the object

3.4 The Reconstruction Process and Generation of Surfaces

The accurate digitization of sculptured surfaces can result in a very high amount of data, possibly even in the order of Giga Bytes of computer memory (Levoy 2000). The computation performance of existing CAD/CAM-systems is insufficient for the processing of this data.

A data reduction is required to solve this problem. A data reduction of more than 80% can be achieved depending on the complexity of the work piece by computing spline -curves and -surfaces using the following algorithms:

- bicubic Bezier,
- polynomial representation (Coons),
- B-Spline,
- Non Uniform Rational B-Splines, (NURBS) representation.

These computer internal representations of the digitized object are obtained by the Advanced Surface Modeling Software Package (ASMOS) developed at the University of Stuttgart and the Higher Technical Institute in Nicosia, Cyprus.

Figure 5. The shaded and freeform structure of the object joined together.

The output of ASMOS can be processed by all 2D / 3D-oriented CAD/CAM-systems. For the data transfer within CAD -systems the following interfaces are available:

- IGES,
- VDAFS and
- STEP.

4. VISUALIZATION AND ANIMATION

4.1 Visualization Introduction

Archaeologists try to document their findings in the best way possible. They use varying techniques, from aerial photographs, Photogrammetry, GPS, to simple hand surveys. They log their findings with precision and try to reconstruct very accurately what was there thousands of years ago. Visualizations of their hypothesis of how things were help them verify and easily communicate to other researchers the reconstruction they have put together. There are many different visualization methods from simple hand drawings, to CAD designs, GIS systems, 3D representations, animations and walkthroughs or even stereoscopic representations in virtual reality applications.

Knyaz and Zheltov (Knyaz and Zheltov, 2001) discuss the different advantages of a virtual reconstruction. Three dimensional and virtual reality representations can be shared over the web or even be viewed through the web. Virtual museums are constantly increasing and new technologies are used for visualization such as photo realistic rendering. Instant sharing over the web with other researchers can help in exchanging opinions with people all over the world, working remotely. Easy accessibility to the public over the web or through educational and entertainment applications also promotes cultural heritage. Furthermore, searching manipulation and correlation of objects is simplified and the original artefacts or monuments are preserved.

Figure 6. An overview of the ancient tomb used as case study

The 3D representation has to provide adequate geometry characteristics and detailed enough textures for the archaeologists to be able to work on them. While the process of creating the virtual models can be complex, there are various techniques that try to automate the whole process as much as possible.

4.2 The Visualization Process

For the rendering of the model the stereoscopic display was used. It is a rear projection screen with mirror and 2 ordinary DLP´s with polarizing lenses, Fig. 7. A 2.4 GHz PC with an Nvidia Quatro4 video card which has output for 2 monitors was used. The system renders one image for each eye, and both images are projected on the screen. The observer uses polarized glasses, which allows him to see only one image for each eye. The observers use polarized glasses, which allow them to see only one image for each eye, thus producing a stereo feeling especially when objects come out of the screen (negative parallax). For the rendering part the model was acquired from the photogrammetric methods and was textured using a texture map of the local stone and grass, in an attempt to show how the environment appears nowadays, Fig. 8. During the visualization process there are two options, to visualize the actual objects or to visualize the reconstructed objects.

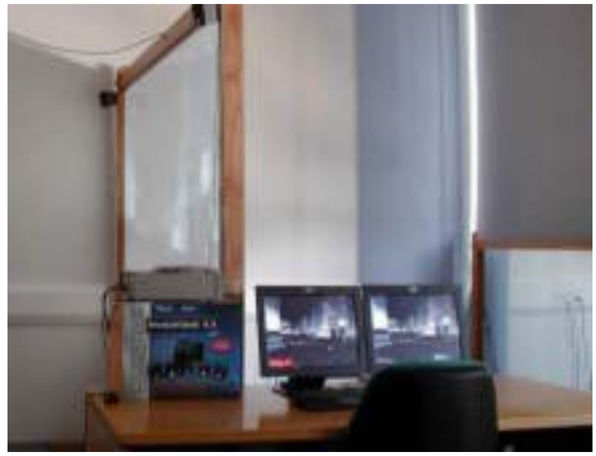

Figure 7. The visualisation set-up, showing the big screen and the mirror. The two monitors are used for control with each one giving a preview of what each eye will see on the big screen

4.3 Animation

The final model is loaded in the virtual reality system and the user can navigate around to examine the tomb. For navigation we use a Polhemus Fastrack tracker and an analogue joystick. Looking at the model in stereo and being able to move around gives a much more complete impression of the tomb and the size of the chambers. The virtual system can be further enhanced with collision detection to give some feedback about the geometry of the objects. A more advanced interface could allow the user to move objects around and try to fit different pieces together.

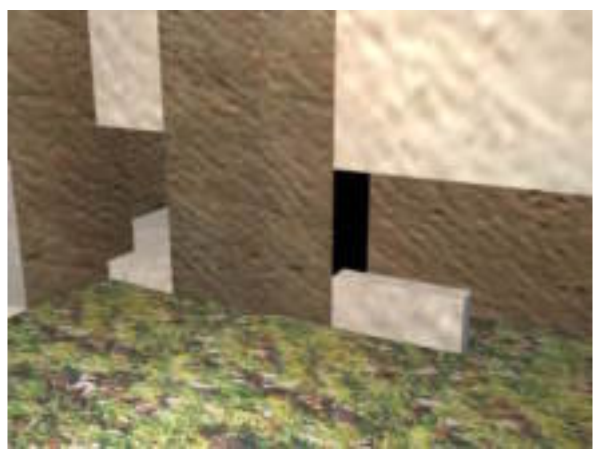

Figure 8. A close-up of the tomb showing certain sections in different colour (with off-white texture). These are components that can be manipulated by the user, e.g. removed, to allow better visualisation

Care should be taken though, as the correctness of the visualization can sometimes be taken for granted (Ogleby, 1999). Different interpretations of archaeological data can result in different reconstructions and the virtual models should be questioned the same way the drawings on paper are questioned. In fact there is an on-going debate on whether striving for photorealism is the right approach when dealing with what is often uncertain data (Strothotte 1999). For eaxmple when doing a reconstruction of an ancient site to show how it was in it's prime, then some go as far as proposing to use non-photorealistic rendering of the 3D models to highlight the fact that what we are showing is an interpretation of how the site might have been and not necessarily a truth to be taken for granted.

The virtual environment could be used to compare two different reconstructions of the same object. By rendering both objects in semi-transparent mode the differences could easily be distinguished. All sorts of interactive tools for archaeologists are possible. The whole process of reconstruction of the missing pieces could be done in virtual mode and then recorded. Finally, the video could be enriched with narrative that describes the whole process and serves as a documentary. Integration with haptics devices is another interesting area. The user would be able to feel the shape of the object and the whole experience becomes more believable (Bergamasco et al, 2002).

5. DISCUSSION-CONCLUSIONS

The paper presents a complete process of converting an archaeological object (i.e. a tomb) to digital representation and exploration of that site in a virtual environment. Starting from scratch the spatial information is collected using photogrammetric techniques. At the following reconstruction techniques applied to create the 3D object model and then visualization and animation techniques to illustrate a true representation of the up to date situation.

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