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AN OPTICAL THREE-DIMENSIONAL MEASURING TECHNIQUE FOR A DETAILED NON-CONTACT DATA ACQUISITION OF OBJECT SURFACES IN THE FIELDS OF CULTURAL HERITAGE, ARCHEOLOGY AND THE CARE AND PRESERVATION OF HISTORIC MONUMENTS

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ABSTRACT:

In archaeology, building research and the preservation of historical monuments there is an increased demand for the use of optical 3D measurement technology for reproduction and documentation (Schaich 2009, p.35). But due to the geometric complexity as well as the uniqueness of the objects, the calculation of the cost of 3D-capturing and processing still poses high risks. The recording of objects is therefore often considered to be too expensive.
For this reason the following two main focuses will be investigated more closely. Firstly a closed process chain will be developed and tested, beginning with the surveying of objects, then modelling followed by virtual visualisation and the real-life reproduction of single objects as well as low-volume production. Secondly an efficiency analysis of the individual processing steps will provide the basis for the optimisation-potential to be deduced. All of the investigations will be applied to objects of differing complexity.

KURZFASSUNG:

In der Archaeologie, Bauforschung und Denkmalpflege gibt es eine erhoehte Nachfrage zum Einsatz optischer 3D-Messtechnik zur Reproduktion und zur Dokumentation (Schaich 2009, S. 35). Doch aufgrund der geometrischen Komplexitaet und der Einzigartigkeit der Objekte ist eine Kostenrechnung fuer die 3D-Erfassung und Weiterverarbeitung heute immer noch mit hohen Risiken behaftet. So wird die Aufnahme der Objekte oft als zu kostspielig eingeschaetzt.
Aus diesem Grund werden die folgenden zwei Schwerpunkte naeher untersucht. Zum einen wird eine geschlossene Prozesskette entwickelt und getestet, die von der Objektvermessung, ueber die Modellierung bis hin zur virtuellen Visualisierung und realen Reproduktion von Einzelstuecken bzw. Kleinserien reicht. Zum anderen erfolgt eine Wirtschaftlichkeitsanalyse der einzelnen Prozessierungsschritte, um dann daraus Optimierungspotenziale abzuleiten. Alle Untersuchungen werden jeweils an unterschiedlich komplexen Objekten durchgefuehrt.

1. INTRODUCTION

The present paper describes the development of a current research project on a contact-free measuring technique for the aquisition of data of surfaces of monuments and other historical objects. The project is run by the 'Beuth Hochschule fuer Technik, Berlin' (part of the 'Forschungsassistenz V'-program, funded by the European Social Fund) and includes an investigation of the economic feasibility of the institute's innovative knowledge and techniques for small- and medium-sized enterprises. The implementation of the project is done in cooperation with 'Lupos3D GbR, Berlin' who specialise in three-dimensional laser scanning and terrestrial photogrammetry and software development.
The 'QTSculpture', a structured-light 3D-scanner developed by 'Polygon Technology, Darmstadt' measures the shape of objects and aquires high-definition data in a contact-free manner.

2. RECORDING PROCESS

A structured-light scanner from the company Polygon Technology GmbH (www.polygon-technology.de) was used to record the objects. The following briefly describes the recording process.

The structured-light projector projects a defined stripe-light pattern onto the object in three frequencies. The pattern is then captured simultaneously by two CCD cameras from different directions. By calibrating the whole measurement system beforehand, corresponding points captured by both cameras can be precisely calculated by triangulation in the super-ordinate coordinate system of the object. With each recording a point cloud is generated. Subsequently the object is captured from different directions. The resulting point clouds are then aligned with each other, either automatically, while recording with the turntable or interactively by specifying starting values in the form of identical points. The resulting 3D point cloud is then triangulated in an automatic process resulting in an exact 3D model. Beyond that, texture recordings are possible. These can be overlaid on the object semi-automatically after the triangle meshing (Akça 2007, p.35-46), (Guehring 2002, p.14-82).

3. APPLICATION POSSIBILITIES AND EXAMPLES

This section presents examples of the different applications of 3D measurement technology. These are divided into three categories: *scientific applications*, *visualisation possibilities* and most particularly *applications for the internet*.

3.1 Scientific Applications

One possible example of a science-based project would be developing a virtual archive, i.e. a database where three-dimensional objects are recorded. This would be conceivable on a small scale with individual collections to improve archiving, documentation and research. Another motivation could be to replace printed catalogues with comparable digital media. One reason for doing so is the fact that the possibilities offered by digital publishing are far superior to those of print media. This can be clearly seen in current international efforts in this area, such as the European Community's 3D-Coform project or the archaeological collection Carnuntum from the Federal State of Lower Austria (www.3d-coform.eu, www.carnuntum-db.at). In these projects a virtual archive for pieces of art and other archaeological finds is being developed. These show the value of optical 3D measurement technology in this area of science.

Whether on a larger or a smaller scale, virtual collections will enable above all researchers to find comparable objects much more easily. These databases should be intelligent and be able to find and link stored objects automatically. Search inquiries, such as information regarding epoch, type of object, source of discovery and specific perimeters such as size, colour and form need to be possible. The database needs to be able to deliver all stored exhibits which correspond to such a search inquiry.

Three-dimensionality has many advantages over today's standard documentation which uses photos with descriptive texts. The textured, truly detailed 3D data record allows scientists to view the object from all sides at any time. It is often the case with photographic documentation that in retrospect you wish you had another image from another perspective.

(Schaich 2009, p.36)

3D data records furthermore provide the possibility of requesting information interactively using user-friendly and freely available viewers (such as Adobe Reader 8.1 from Adobe: www.adobe.com, or Deep Viewer from Right Hemisphere: www.righthemisphere.com). As Figure 1 shows, very simple cuts and measurements can be generated. It is also possible to place commentaries directly onto the model and to change the viewing mode with a simple mouse click.

Figure 1. User-friendly representation of a small antique figure using the software Deep Viewer (original in the Archaeologisches Landesmuseum im Paulikloster, Brandenburg)

Extensive commercial 3D software (e.g. LupoScan from Lupos3D: www.lupos3d.de or RapidForm from INUS Technology: www.rapidform.com) can also carry out desired/actual comparisons, i.e. a comparison of the copy and the original, as well as calculate 3D data as a plane, cylinder or sphere (see Figure 2). To show the distance from each single point to the regulating body, each point has a colour relating to the distance.

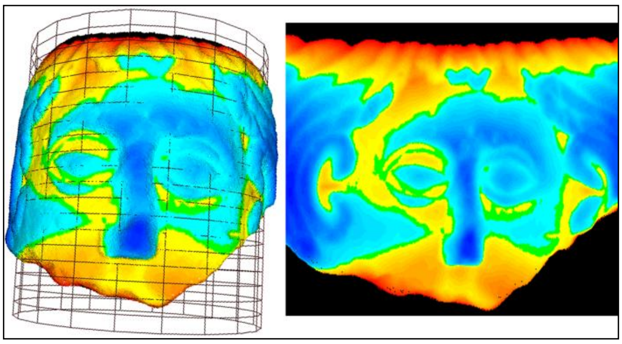

Figure 2. Calculation with LupoScan. Left: Angel's head (Figure 3) in relation to a cylinder. Right: Unrolled representation (original in the Archaeologisches Landesmuseum im Paulikloster, Brandenburg)

3.2 Visualisation Possibilities

The visualisation of 3D objects opens up whole new possibilities for advertising, particularly for museums. Museum visitors can access 3D objects on the museum's website and are able quite simply and intuitively to view, rotate and understand them. The new presentation technology is hoped to raise people's interest to visit the museum, rather than – which one might fear - replacing the visit. 3D animations of museum exhibits can contribute to an understanding of the object and provide visitors with a context, also relating to the fourth dimension: time. Using special techniques, known from the latest 3D films (Avatar, Ice Age and Alice in Wonderland) virtual 3D objects can be represented in 3D and viewed from all perspectives. 'Vases, historical spears or even whole temples can be animated three-dimensionally. In years to come museum visitors will be able to rotate Roman amphorae on a screen or fly around a temple.' (Fraunhofer-Gesellschaft, 2009). The beginnings are already there. One good example is the Virtual Hampson Museum (www.hampsonmuseum.cast.uark.edu) in Arkansas/USA. Recording objects in 3D also enables the production of geometrically exact copies. These can be arbitrarily resized. 3D printers offer the simplest method of producing real-life 3D objects. These are very well suited to producing very small (centimetre-scale) to middle-sized (25cm x 20cm x 35cm) objects. Colour 3D prints are also possible with the newest 3D printers, with which it is also possible to make textured models (Z Corporation, 2010).

CNC milling machines enable an increase in precision and quality of material as well as greater flexibility of size. One very good example is the copy of the statue of Constantine the Great (Schaich 2007).

3.3 Applications for the Internet

Most institutions, companies and museums present themselves nowadays in the internet using it for advertising, communication, presentation of results and publicity. In the

areas of archaeology, the preservation of historical monuments and building research the internet is used almost exclusively in 2D, i.e. with pictures and descriptions. Only very few, e.g. the Hampson Museum (see above) work with the third dimension, and even with the fourth – time.
As we can see in the afore-mentioned Virtual Hampson Museum, all three-dimensionally captured objects can be represented in impressively high resolution and also with texture using animations or Adobe 3D PDF. In order to maintain a high level of performance in rotating, moving, zooming and measuring, the resolution is rarely 100 percent, but is clearly lower in order to limit the volume of data. Higher resolution data should also be offered as a download in VRML/OBJ/STL-format. Freely available 3D viewers are widespread. In our experience the best known viewers (VRML-View, GLC-Player, Mesh-Lab, BS Contact, Deep View) offer more options than merely looking at the object.
The website of a research project on this subject at the Beuth University for Applied Sciences, Berlin serves as an example of further possibilities for online presentation. It will shortly be published and will be available at the following address: (www.beuth-hochschule.de/forschungsassistenz → Forschungsassistenz V → Fachbereich III) and (www.lupos3d.de).

4. PROCESS CHAIN AND EFFICIENCY ANALYSIS

4.1 Developing and testing a Process Chain

The time needed from recording to the final product varies and always needs to be calculated individually with reference to the object. However a certain level of standardisation is possible. To simplify things the whole process can be divided into the following individual operations:

- Planning (object analysis, planning of the recording)
- Data Capturing
  - 3D-Data capturing
  - Pre-registration
  - Texture capturing
- Data Processing
  - Registration
  - Triangulation
  - Optimising
  - Texturing
- Extras
  - Production of replicas (3D printing, milling)
  - Video or interactive animation
  - Online presentation

The data capturing is divided into geometric data capturing (3D data capturing), pre-registration and texture capturing, whereby the latter already takes up a large amount of time during the 3D data capturing. The data processing is divided into registration, triangulation, optimising and texturing. Again the largest amount of time taken for the registration is during the 3D data capturing. This is because the pre-registration almost always takes place parallel to the geometric data capturing in order to avoid holes (areas that have not yet been captured) in the point cloud. The production of texture is optional. ‘Extras’ lists the time taken for the production of different results. These can be the production of copies, animations or online presentations. With the production of replicas using 3D printing or milling the time needed is dependent on the volume and complexity of the objects. The conditions regarding the data for printing and milling are usually met automatically by the software that is used. So-called ‘waterproof’ models are expected. The production of copies with CNC milling machines is usually carried out by specialists who have the necessary skills in machine programming. On the other hand, 3D printing is a comparatively simply operation, although a special 3D printer is necessary.
The production of videos or interactive animations can vary so much that it is very difficult to offer general time specifications. Animations range from simple videos in which the object rotates on its own axis, to short films of several minutes with background images, music, speech and a storyline. However it is usually always worth the effort: using animations with movement, zoom, sound and other methods it is possible to generate interest and to guide the viewer’s attention to the most essential things.
The Adobe 3D PDF format offers a simple online embedding of 3D objects. This can be carried out in a matter of minutes. It is also no problem to make high-resolution objects available as downloads.

4.2 Time Needed for the individual operations

The necessary time was examined using three concrete examples, the results of which are in Table 6. The three objects provide examples of three different classes of object which differ from one another in size, material, resolution and complexity. This classification is vital for determining the time needed. Through size and resolution it is possible to make a rough estimate regarding the time necessary for the operation. But it still remains that the material, the surface properties and the complexity are important factors which can significantly influence the time needed.
When calculating the amount of time needed, it is important to include the time needed to prepare the measurement system, i.e. setting-up and calibration. Setting up and calibrating the structured-light scanner from Polygon Technology GmbH (www.polygon-technology.de) needs around an hour. If several objects with the same resolution are being recorded, then a repeated calibration is not necessary. In this case, the time taken is relative to the number of objects being recorded. The times given in Table 6 exclude this preparation time.
The first and most simple example is of an angel’s head, about the size of a fist, made of stone and from the 10^{th}-11^{th} century. It was recorded at the Archaeologisches Landesmuseum im Paulikloster in Brandenburg (see Figure 3). Table 6 shows the short time needed for recording and processing. This was due to the condition of the object and the resolution requirements: there were no indentations or filigree parts and the object only needed to be precise to around a tenth of a millimetre.

Figure 3. Angel's head, 10th-11th Century (original in the Archaeologisches Landesmuseum im Paulikloster, Brandenburg)

The second example is life-size: a bust of Peter Christian Wilhelm Beuth (1781-1853), after whom the Beuth University of Applied Sciences is named. The size alone meant that a significantly greater amount of time was needed for the recording and the post-processing. There were indentations at the hairline and the ears, which complicated the recording and the post-processing. The time needed for triangulation and optimising could be relativised by frequent use of automatic processes, but the results still needed to be revised and the parameters adjusted several times.

Figure 4. Life-size bust of P.C.W. Beuth (original in the Beuth University of Applied Sciences, Berlin)

The Praying Boy is the largest and most complex object in this series (1,4m high). The recording process turned out to be complicated not only because of the size but also due to the many indentations and filigree parts (fingers, feet). Modelling these took a considerable amount of extra time, particularly for post-processing. Then there was the difficult texturing which even with QTSculpture-Software, a highly efficient texturing tool from Polygon Technology Gmbh (see above) needed a high level of effort, time and experience.

Figure 5. Replica of the Praying Boy at the south west churchyard in Stahnsdorf

Time needed for objects of different classes	Angel's head	Beuth bust	Praying Boy
3D Data capturing/ Pre-registration	1h	2h	4,5h
Texture recording	0,5h	-	3,5h
Registration/Triangulation	5 min	2h	4h
Optimising	0h	4h	4h
Texturing	1h	-	9h
Total Time	**2,5h**	**8h**	**25h**

Table 6. Time Needed

5. CONCLUSION AND OUTLOOK

Optical 3D measurement technology has long been in use in industry and now offers new possibilities to museums, archaeology, the preservation of historical monuments and building research. Over the last ten months these possibilities have been examined by the Beuth University of Applied Sciences, Berlin. During the University's research project appropriate and exemplary objects from archaeology and monument preservation were recorded. Using these examples, process chains were developed and optimised in order to make more qualified and quantified estimates of the time needed for the operation and subsequently the cost. In this respect, the propositions made here constitute only intermediate results. In the remaining eight months of the research project the process chain will be further optimised. Furthermore there will be an emphasis on an efficiency analysis as well as a comparison with other 3D measurement systems.

6. REFERENCES

AKCA, D. et.al. (2007) Performance evaluation of a coded structured light system for cultural heritage applications, In: Beraldin, Remondino, Shortis (Hrsg.): Videometrics IX, Proc. of SPIE-IS&T Electronic Imaging www.photogrammetry.ethz.ch/general/persons/devrim/2007US_Akca_etal_Videometrics.pdf (accessed 31.3.2010).

Fraunhofer-Gesellschaft (2009) Der dreidimensionale Museumskatalog, Archaeologie Online www.archaeologie-online.de/magazin/nachrichten/view/der-dreidimensionale-museumskatalog (accessed 31.3.2010).

Guehring J. (2002) 3D-Erfassung und Objektrekonstruktion mittels Streifenprojektion, Dissertation eingereicht bei der Fakultaet fuer Bauingenieur- und Vermessungswesen der Universitaet Stuttgart, Germany www.elib.uni-stuttgart.de/opus/volltexte/2006/2715/pdf/Guehring_diss.pdf (accessed 31.3.2010).

Schaich, M. (2009): 3D-Scanning-Technologien in der Bau- und Kunstdenkmalpflege und der Archaeologischen Feld- und Objektdokumentation, In: Faulstich, Hahn-Weishaupt (Hrsg.): Dokumentation und Innovation bei der Erfassung von Kulturguetern Schriften des Bundesverbands freiberuflicher Kulturwissenschaftler Band 2 (2009), S. 35-46.

Schaich, m. (2007), Case Study: Das "Konstantin-Projekt". 3D-HighTech-Verfahren in der Archaeologie. 3D-Scanning, 3D-Modellierung, 3D-Rekonstruktion, 3D-Reproduktion. www.arctron.de/3D-Vermessung/3D-Laserscanning/Beispiele/Konstantin/PresseArcTron3D.pdf (accessed 31.3.20109).

Z Corporation (2010): Funktionsweise des 3D-Drucks. Die Vision, die Innovation und die Technologien hinter dem Tintenstrahl-3D-Druckverfahren. www.zprinter.de (accessed 31.3.20109).

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