COMPARISON OF DIFFERENT METHODS FOR SCULPTURE RECORDING

Guido Heinz
i3mainz, Institute for spatial information and surveying techniques
Fachhochschule Mainz
Holzstrasse 36, D-55116 Mainz, Germany

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ABSTRACT

Ancient sculptures and findings play an important role in archaeological research. The survey of these objects includes information on size and shape. Digital object models can provide the basis for measurements, visualizations and copies, when the object itself is not available.
The object of the investigation is a copy of a Roman gravestone from the 2nd century AD (fig. 1). It has been chosen because it has different surface types with flat and steep, rough and smooth regions. Different methods are compared for their suitability to record these different types of surfaces.
Analytical and digital photogrammetric techniques have been used as well as systems designed for industrial measurements.
In the paper, the methods are compared with regard to efficiency and accuracy. Examples of the results and differences between the systems are shown.

KURZFASSUNG

Antike Skulpturen und Funde spielen in der archäologischen Forschung eine wichtige Rolle. Zur Untersuchung dieser Objekte gehören auch Angaben über Größe und Form. Falls die Objekte selbst nicht zur Verfügung stehen, können digitale Objektmodelle die Basis für Messungen, Visualisierungen und Reproduktionen darstellen.
Das Objekt für diese Untersuchung ist die Kopie eines römischen Grabsteins aus dem zweiten Jahrhundert n.Chr. (fig. 1). Er wurde ausgesucht, weil er verschiedene Oberflächenbeschaffenheiten aufweist. Es gibt flache und steile sowie glatte und rauhe Abschnitte. Unterschiedliche Methoden wurden auf ihre Eignung zur Aufnahme dieser unterschiedlichen Oberflächen untersucht.
Neben analytischen und digitalen photogrammetrischen Verfahren wurden auch Industriemeßsysteme eingesetzt.
In diesem Artikel werden die verschiedenen Methoden in Bezug auf Effizienz und Genauigkeit hin miteinander verglichen. Beispiele der Ergebnisse und Unterschiede zwischen den einzelnen Systemen werden aufgezeigt.

INTRODUCTION

Accurate geometric recording is an important part of the survey of ancient sculptures. It is necessary for the comparison of different sculptures.
Many objects are copied to make them accessible for scientists and interested laymen.
The geometric documentation is not complete without an object model suitable for measurements, visualizations and reconstructions. Valuable originals with paintings and sensitive surfaces have to be treated very carefully. Standard techniques for recording or reproduction like taking an impression cannot be used in these cases.

As the objects do not have parametrical shapes, a dense grid of points is necessary to describe the surface with the accuracy required. Possible methods either use visual information of the object or need to touch single object points and record their position.
Touch free methods are photogrammetric, pattern projecting and laser scanning techniques; tactile methods are two mobile coordinate measuring machines.
These techniques can supply suitable digital object models (DOMs).

Figure 1: Gravestone with control points. (Photo: Kuerten)

Preparation

In order to compare the different methods, several control points have been marked. A few selected at the edges were coordinated by forward intersection, the other ones were intended as tiepoints and coordinated in the bundle adjustment for the camera calibration. The points have been designed for the use with different methods, printed on paper and fixed with double sided adhesive tape. For this special object it was possible to stick these points onto the object itself, in case of sensitive surfaces control points may be marked using a frame around the object.

Photogrammetry

Cameras

Different camera configurations have been used to take photographs of the sculpture:

- Zeiss TMK 6
- Rollei 6006 metric with 120 mm lens
- Rollei 6006 metric with 50 mm lens
- Rollei Q16 metric with 50 mm lens

The TMK 6 is a fix-focus camera for terrestrial photogrammetry and uses 9 x 12 cm^2 glass plates. Standard 100 ASA plates have been used with this camera.

The Rollei 6006 metric is a 6 x 6 cm^2 middle format camera with a 11 x 11 réseau grid and rastered focussing lenses. Standard 50 ASA roll films have been used.
The Rollei Q16 metric digital camera was still in development at the time of the photo recording. The construction corresponds to the 6006 metric. The film magazine is replaced by a CCD chip with 4096 x 4096 pixels (15 x 15 μm^2).

Photo Configuration

The mean exposure distances of 75 cm (50 mm lens) and 150 cm (120 mm lens) result in image scales of about 1 : 13 for the Rollei cameras. The base length was chosen to 25 cm (50 mm lens) respectively 12 cm (120 mm lens) giving an overlap for adjacent images of 80 %. With the Rollei cameras a strip of photos along the mean axis of the stone was recorded plus two additional oblique photos to stabilise the triangulation.
Due to the larger format of the TMK 6, four photos covered the whole stone at a mean exposure distance of 60 cm, a base length of 14 cm and an image scale of about 1 : 10.

Image quality

The quality of the digital recorded photos seems to be much better than that of the scanned analogue ones. The photos can be controlled at the time of recording and contrast and sharpness can easily be adjusted.
On the other hand the quality of the analogue photos is influenced by different facts:

- the impact of the settings of the camera on the photos cannot be controlled at the time of photo recording
- the development process is not under complete control of the user
- as common developer and fixer are not optimal for the standard TMK glass plates, the images tend to be rather flat with low contrast
- the réseau grid of the Rollei 6006 metric influences digital image processing techniques.

The glass plates of the TMK 6 have not been used in the further steps because of their very low contrast.

Photo orientation

The marked points have been measured with an analytical plotter in the analogue photos and standard image processing software in the digital photos.
The coordinates of the tiepoints, the orientation parameters of the photos and the interior orientations of the cameras have been calculated in a bundle adjustment with an internal precision of σ_0 = 8.5 µm for the image measurements and $\sigma_{X,Y,Z}$ = 0.09 mm for the object points. These results have been used for all further measurements with software and analytical plotter.

OrthoMAX	No of points	good %	fair %	poor %	interpolated % *
Rollei 6006	630498	8,90	20,63	11,58	58,88
Rollei Q16	697447	28,50	40,65	8,65	22,15

* points not measured

ARCOS	No of points	No of rejected points	%
Rollei 6006	569980	44039	7,72
Rollei Q16	570637	1648	0,29

Figure 2: Results of OrthoMAX and ARCOS

Measurements with the analytical plotter

For the complete stone a 2 cm spacing point grid has been measured. The time consumption for this very coarse measurement with 10.297 object points has shown that an accurate object model with a point spacing of max. 1 mm cannot be performed using analogue techniques within acceptable periods.

Digital photogrammetric techniques

The analogue films and plates have been scanned using a Zeiss SCAI photogrammetrical scanner at a resolution of 15 µm. For the further investigation, only the Rollei 6006 and Rollei Q16 photos recorded with 50 mm lenses have been used to have comparable material.
Two software packages have been used for the extraction of digital object models:
OrthoMAX by Vision International and ARCOS [Boochs, 1987]. Both programs use an area based matching strategy and calculate a regular point grid.
OrthoMAX is distributed as an add-on module to the image processing software ERDAS Imagine. Several parameter settings of OrthoMAX are limited and document that the software is designed mainly for standard configurations with aerial or satellite images. The window size e.g. is limited to 21 pixels, what leads to a high rate of points with low correlation coefficient in this special case.
ARCOS has a greater flexibility at the cost of a more complicated operating. The software is not sold commercially and has been used only for research purposes so far. The results for special configurations are superior compared to those acquired using the standard software.
The results in figure 2 confirm the different image quality of the digital recorded and the scanned analogue images. Reasons for these differences are defects in the images caused by the réseau crosses, dust on the photos and the scanning process itself.

Results of the digital photogrammetry

Fig. 3 and 4 show two typical sections. The sections are based on raw data material without any filtering.
Figure 3 shows the results of ARCOS with different images for a flat region with a scale ratio of 1 : 10 in the figure. It is the part of the stone with the inscription and thus shows small edges. The number of blunders within the scanned images is much higher as compared to the digital recorded images, especially near the edges.
Figure 4 shows a region of the sculpture with big differences in height and compares the results of OrthoMAX and ARCOS. The shape has been calculated quite good, but errors are clearly visible.
The histograms of two difference models are shown in figure 5. They correspond to the regions of the sections in fig. 3 and 4. The left histogram shows an even course with extreme values of about 1 mm, the right one shows values of up to 3 mm documenting correlation errors in the steep parts.
The results of digital photogrammetric techniques must be checked very carefully e.g. by visualizing the point grid with isolines superimposed onto the image information (fig. 6).

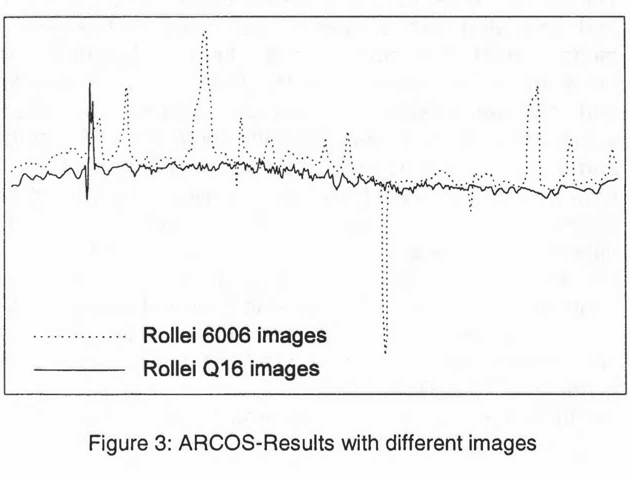

Figure 3: ARCOS-Results with different images

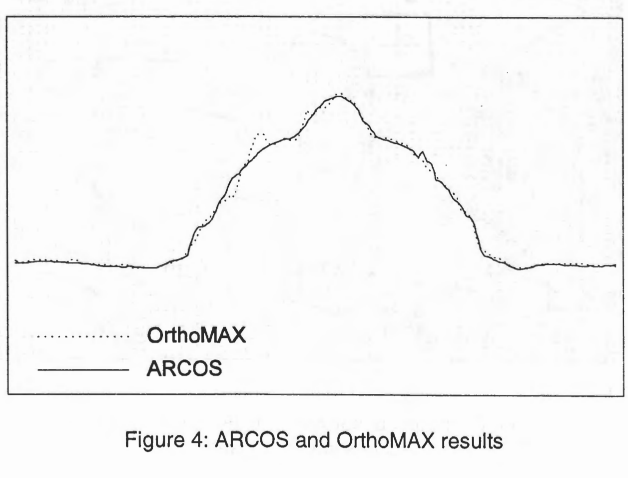

Figure 4: ARCOS and OrthoMAX results

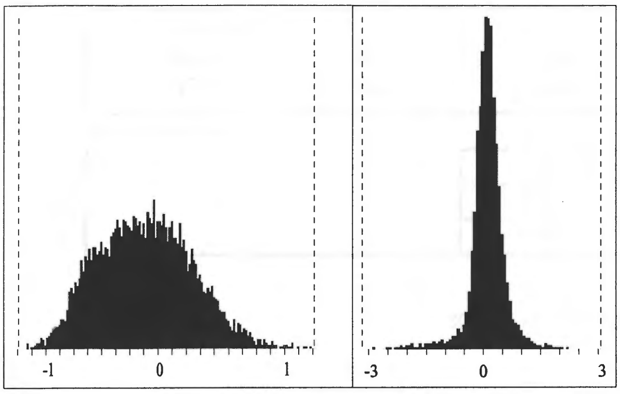

Fig. 5: Histogram of differences between OrthoMAX and ARCOS

Tactile Measurement Systems

Two different tactile measurement systems have been tested. Both of them are designed for industrial measurements and record single points.
The FARO-ARM is a portable coordinate measuring machine that is mainly used in aircraft construction. The arm consists of aluminium parts connected with six precision hinges. The arm can be equipped with different sensors. The accuracy of a single point measurement is about 0.1 mm.
The Metronor MNS uses two cameras to determine the position of the sensor on a grip with several LEDs whose positions in the images are measured. Photogrammetrical techniques are used for the orientation of the system.
Due to several reasons such systems are not suitable for this kind of object:

- Needle sensors tend to scratch the surface of the object, what cannot be accepted for ancient sculptures.

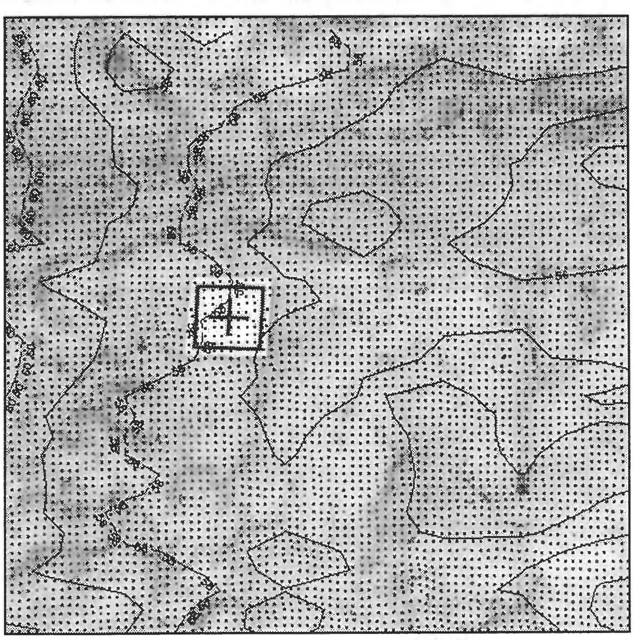

Figure 6: Image subset with matched point grid and isolines superimposed

- Sensors with spheres, e.g. 3 mm ruby spheres, always lead to an offset between the registered point and the object itself. This offset can easily be reduced for parametrical shapes but is a problem for irregular objects, especially as just single points without topological information are recorded. Fine details cannot be recorded with these sensors as not accessible with the sphere sensor.
- As every single point of the object has to be touched with the sensor, the measurement is quite boring and very time consuming.

Because of that the results of these systems were not used for further analysis.

Laser Scanning Systems

Another system tested is a laser scanner developed at the Institute for Navigation of the University of Stuttgart. This scanner records 3D-coordinates and the intensity of reflection for every single point. The laser beam can be turned aside in two dimensions and in that way scan the surface of objects. The system is controlled by a PC and may be used in batch mode. A single scan is limited to 800 x 800 points and takes about 10 minutes.
The accuracy is about 0.1 mm for a distance between scanner and object of 1 m.
Eight scans were made to cover the complete stone and additional three detail scans. Including test scans altogether about 7.7 million points were recorded.
For every single point measurement the object must reflect the laser light back to the system. This means that only diffuse reflecting objects can be scanned what is not a problem for most ancient sculptures. As the intensity of the reflected signal is recorded, the result of the measurement contains gray value information for every single point what may be used for visualizations (fig. 7).
The points are determined in a local coordinate system and have to be transformed if special coordinate systems are required.
The system works completely without touching the object.

Other Systems

The ATOS-System uses the projection of light stripes of different widths to derive object models [Riechmann, Thielbeer, 1997]. These stripes on the object surface are recorded with two CCD-Cameras and processed in a PC. The two cameras and the projector are mounted on a bar and calibrated with a special test object before every measurement. The calibration is almost automated and takes only a few minutes. The length of the bar is variable and can be adapted to different scales. The used configuration records A4 size with about 250.000 points and an accuracy of ±50 µm in a single measurement.
After the pictures have been taken, a visual control with a coarse point grid is possible on the screen to check if the object is recorded completely. The fine point grid is calculated after all photos have been taken within a few minutes. The system needs marked retroreflecting points to transform several single measurements together in one coordinate system. These points have been coordinated by means of bundle adjustment.
As the images of the CCD-Cameras are stored in the PC, they can be used for visualizations.

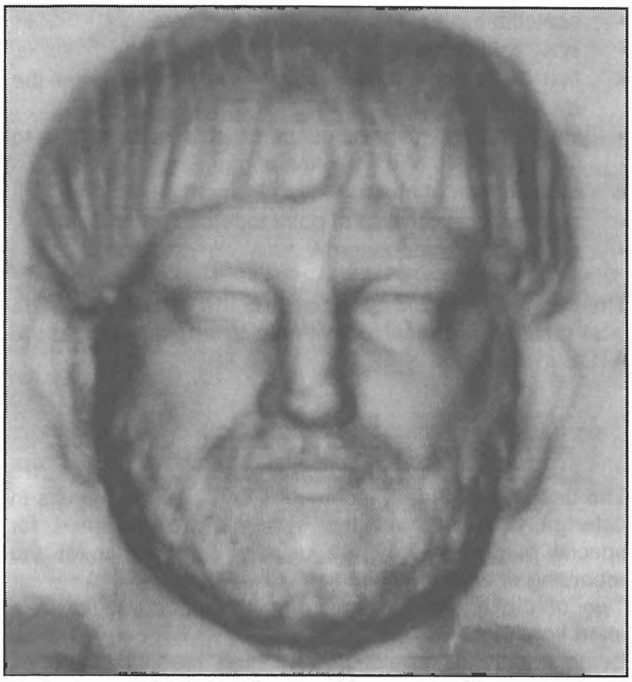

Figure 7: Orthophoto derived from laser scanner data

In selected parts of the stone about 1.9 million points have been measured.
Figure 8 shows an isoline representation of a part of the inscription recorded with the ATOS system. The single letters can be read and demonstrate the high accuracy of the system.

COMPARISON OF THE SYSTEMS

Several points have to be taken into account in order to compare the different systems. Figure 10 lists some specifications of the systems. For all systems trained staff is necessary. Especially the correlation process with the photogrammetric techniques is difficult if standard

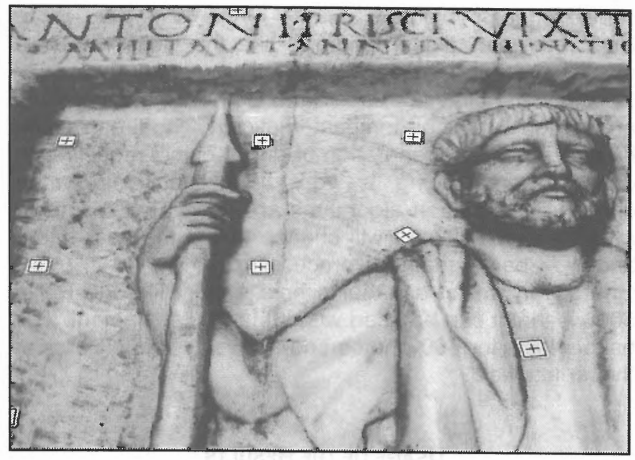

Figure 9: Perspective view of a part of the sculpture. Generated with OrthoMAX data

software is used that is not optimised for these special tasks.
In the tested configurations only the laser scanner could work without touching the object at all. The other systems need control points, which can be marked around the object using a frame.
A high number of points was necessary to describe the object with sufficient details and accuracy. Methods with single point measurements like the tactile systems and the use of an analytical plotter cannot fulfil this at affordable time.
It is very important that the user can control the recorded data. This control should take place during or immediately after the measurement and implies, that the final DOM is generated at least within several minutes or half an hour. The laser scanner, the FARO-Arm and the ATOS system provide tools for a visual control.
One disadvantage of the photogrammetric techniques is the DOM generation after the recording. The result after leaving the sculpture are just photos that do not show any information on the object geometry by this time. Analogue films even have to be developed and scanned. Digital cameras provide images immediately and allow a quality control. The used software is not designed for the special purposes of sculpture recording and thus is not the first

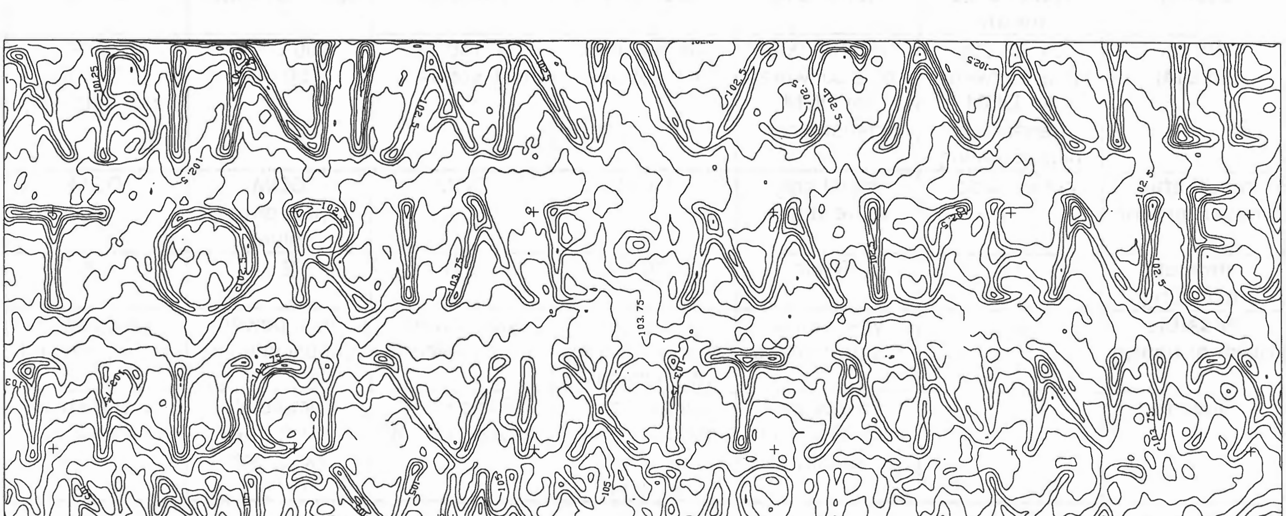

Figure 8: Isoline representation of the ATOS data of a part of the inscription

choice for such objects.
High resolution digital cameras like the Rollei Q16 are often used for single point measurements. Especially when coded points are used and the photo measurements are carried out full or semi automatically, good results can be expected. The generation of digital object models with dense point spacing is very time consuming when common correlation algorithms are used. Developments in Hard- and Software will change this in the near future and allow nearly real-time processing.
One advantage of a rather simple system like the Rollei 6006 is that it can be used without further equipment. The battery lasts for 600 photos and allows to take pictures in the remote field.

USAGE OF THE RESULTS

The usage of the results is dependent on the shape of the object. Flat objects like this gravestone can be handled with 2 ½ D object models. Building topology information can be done using triangulations. Standard products can be used for visualizations like orthophoto generation, perspective views, draping of image information over the model etc. (cf. fig. 7, fig. 9). Measurement can easily be performed in these models with a defined reference plane. Volume objects are more difficult to handle and require different data models [Boochs, Heinz, 1996] and methods to generate topology information of the surface.
The digital object models can be used to produce copies with milling machines. The quality depends on the object model. A model with a mean point spacing of 1 mm cannot show all fine details of the original of course. But it can be a good basis for final detail work made by hand.

DEMANDS FOR SYSTEMS

The optimal system for sculpture recording should fulfil several demands:

- measurements without touching the object
- high density of recorded points
- scalable system for different object sizes
- easy calibration of the system
- fast DOM generation during or immediately after the measurement
- visual control of the measurements with regard to completeness and detection of blunders
- combination of multiple measurements
- automatic generation of point topology information
- possible outdoor usage

The optimal system was not among the tested ones. The best results were received with the laser scanner and the ATOS system.

CONCLUSIONS

The usage of standard techniques and systems results in different problems. As the systems are designed for special purposes, they are usually not optimal for the recording of ancient sculptures.
Two of the tested systems provided good results in a short time.
Using matching correlation with high resolution images comes up with reasonable results, but they are time consuming and the object model has to be checked carefully.
Single point measurements cannot be used for the generation of appropriate models as the measurement takes too much time.
Rather new systems like the laser scanner or ATOS are promising and should be taken into consideration in the future.
System providers will have to design respectively improve user friendly interfaces and tools for tasks like easy calibration, combination of several object systems or the building of topology.

System	Rollei 6006 metric	Rollei Q16	Metronor MNS	FARO-Arm	Laser Scanner	ATOS
Price (in DM)	ca. 25.000 plus software for DOM generation plus scanning	ca. 130.000 plus software for DOM generation	ca. 500.000 incl. software	ca. 100.000 incl. software	100.000 – 150.000	150.000 – 200.000 incl. software
result after measurement	colour slides	digital gray value image	DOM	DOM	DOM plus gray values	DOM
time of recording	1 h	45 min	10 h	8 h	2 h	1 h
Possible outdoor usage	yes	yes, power supply needed	yes, power supply needed, no humidity	yes, power supply needed	yes, power supply needed	yes, power supply needed
Special		Prototype excellent image quality	single point measurement, no direct sunlight	single point measurement	completely touch free, no direct sunlight	user friendly software

Figure 10: Comparison of some specifications of the tested systems

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- Institute for Navigation, University of Stuttgart, (Laser Scanner)
- Metronom GmbH, Mainz (FARO-ARM, Metronor MNS)
- Rollei Fototechnic, Braunschweig, (Photos Rollei Q16)

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REFERENCES

BOOCHS, F., 1987: Off-line compilation of Photogrammetric Stereo models using digital image correlation. Photogrammetria, Vol 41, 1987, pp. 183 - 199.

BOOCHS, F., HEINZ, G., 1996: Generation and Use of Digital Surface Models for Volume Objects. International Archives of Photogrammetry and Remote Sensing, Volume XXXI, Part B3, Commission III, pp. 70 – 76.

KÜRTEN, ANGELA, 1998: Vergleich verschiedener Verfahren zur Erzeugung digitaler Objektmodelle. Diplomarbeit FH Mainz (unpublished).

RIECHMANN, W., THIELBEER, B., 1997: Hochauflösende Oberflächenerfassung durch Photogrammetrie und Streifenprojektion. Photogrammetrie Fernerkundung Geoinformation. Jahrgang 1997, Heft 3, S. 155 - 164