MONOTORING THE WEATHERING OF STONES: SETUP AND FIRST RESULTS

Michael Kempa

Institute of Photogrammetry and Cartography, TH Darmstadt, FRG

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ABSTRACT

A lot of architectural monuments of the Middle Ages are threatened by continuous pollution, especially facades by weathering of stones. Initialized by the Institute for Preservation of Stones in Wiesbaden (FRG) photogrammetric measurements were made to get numerical information about this process at the romanic monastery Limburg - partly destroyed by a fire since the 16th century. Parts of stones on a cross column were selected and a comparison of two surfaces with a time delay of one year has to be photogrammetically generated. Because of the high accuracy demanded for this task (about 0.1-0.3mm) two terrestrial survey cameras (Wild P32) were modified and calibrated for this close-range application (image scale about 1:8). The procedure and first results (numerically and graphics) will be presented.

KEYWORDS

Architectural, Calibration, Close-Range, DEM

INTRODUCTION

A lot of architectural monuments of the middle ages are threatened by continuous pollution. This concerns entire facades as well as small details of cultural-historical importance. Curators of monuments are confronted since a longer time with this problem und cooperate with experts of scientific disciplines (chemical engineers, mineralogists etc.). Thus chemical and environmental influences and causes are searched but in this way no statement is possible about the quantity of the weathering process during a fixed period. Hence, for curators of monuments this is a first indicator if precautional measures against the weathering of stones are necessary or not.

PARTICIPANTS AND HISTORY OF THE OBJECT

Two years ago the Institute for Preservation of Stones (IfS) was founded. Its main tasks are chemical and mineralogical research work. In addition a pilot project initiated by Dr. Kraus with the Institute of Photogrammetry (TH Darmstadt) was defined: surfaces of natural stones are surveyed photogrammetically to get information about the quantity of loss caused by weathering. As test object parts of stones were chosen on a cross column of the monastery Limburg a. d. Haardt (close to Bad Dürkheim / Pfalz, s. fig. 1). The time delay between two surveyings is a little bit more than one year.

The former monastery Limburg is a foundation of the emperor Konrad II. and was build up between 1025-1042. It was destroyed for the most part by a great fire in the beginning of the 16th century. Afterwards the church was only rebuilt incompletely */DEHIO 1984/*. Since that the nave without roof is exposed to the weather (s. fig. 2). Since 1969 restoration is carried out but refer only to the brickwork. Almost all of the original stone surfaces, hewed in the stonemason-technique of the 11th century and very often similar to a herringbone pattern, are destroyed and completely washed out */Dölling 1979/*.

Surfaces of natural stones have already been surveyed with photogrammetric measuring techniques. There, either the classification of different zones of varying level of damage or the determination of the loss of surface were carried out, s. */Heckes et al. 1988, Grassegger, Eckstein 1990, Mauelshagen , Strackenbrock 1990, Strackenbrock et al. 1990/*. The results and experiences have shown that the quantitiy of the weathering process can be evaluated by close-range photogrammetry.

In the following the own approach for surveying surfaces of natural stones is presented: equipment, measuring design and first results of one epoche. The comparison between two epoches and quantities concernig the waethering process are not yet finished. However, the results will be presented just intime at the ISPRS congress in Washington.

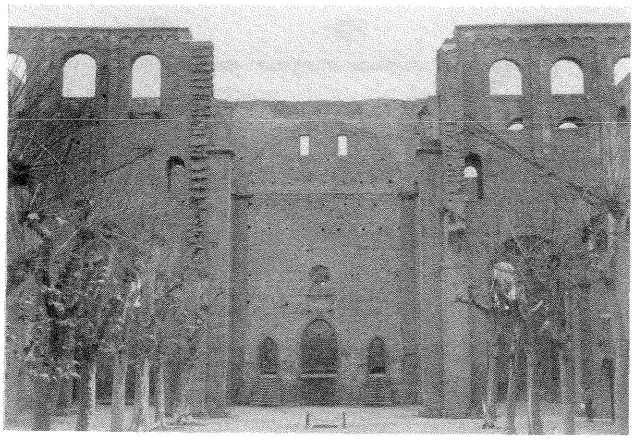

figure 1: the nave (overview, left) and the cross column containing the test objects (more detailed, right)

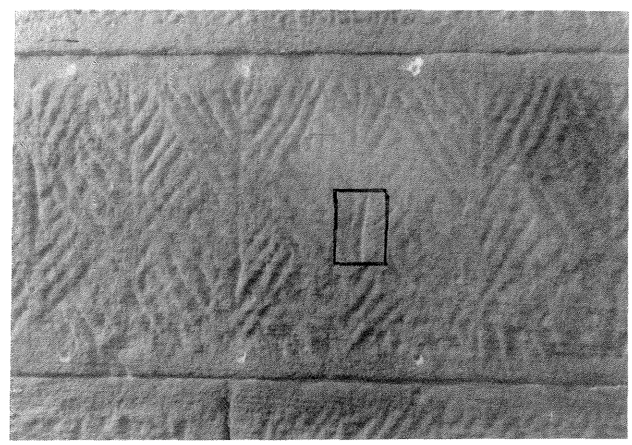

figure 2: natural stones with different level of weathering

CLAIMS, CHOICE OF SURFACES AND PHOTOGRAMMETRIC TASKS

After an initial inspecting of the test object six parts on the cross column were chosen and spread over all directions to get information about an influence of the position. Any portion covers an area about 20*20 cm^2. The chosen surfaces also differ due the level of weathering (s. fig. 2). This was done because it is possible that form and quantity vary in different phases of the weathering process.

The curators of monuments restricted the number of control points per area and required a respectful treating of the historical environment. Because a priori no statement about the account of the assumed loss of surface could be made by the cooperating mineralogists the range of accuracy was fixed to 0.1-0.3 mm.

The photogrammetric camera

To apply two photogrammetric cameras (Wild P32) for the tasks described above some modifications had been caried out. The focal length was changed to achieve an image scale of about 1:8 (i.e. a distance of 60 cm to the stone). It was realised by inserting metal cones. Afterwards the depth of focus range was determined empirically using an optical bench. In this case the range is very small and it should be guaranteed that the range of differences in elevation on the test object (max. 5 cm) is within it and the desired distance to the object can be realised.

After this modification the two survey cameras were calibrated using a testfield (s. fig. 4). An alraedy existing testfield (metal plate with borings to insert control points) was modified to adapt the differences in elevation to the new conditions. For both cameras in each case 8 photos were taken for the calibration procedure (s. tab. 1). The control points were introduced in a bundle block adjustment with a standard deviation of 0.1 mm in X and Y, 0.2 mm in Z. The results are summarized in table 2.

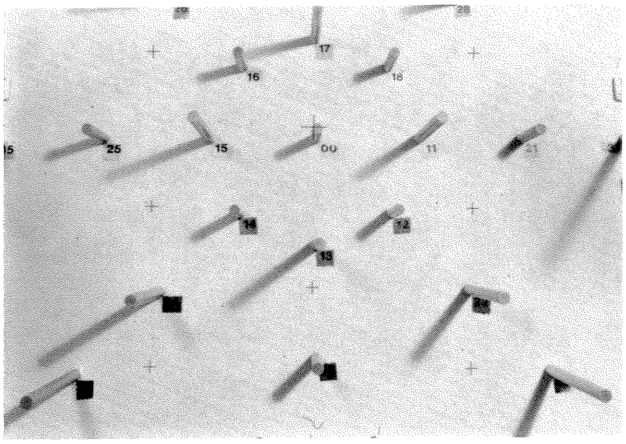

figure 3: testfield used for calibration

	omega	phi	kappa	dX0(m)	dY0(m)
photo1	0	0	0	0	0
2	0	0	200	0	0
3	0	0	300	0	0
4	0	0	100	0	0
5	+20	0	300	+0.1	0
6	-20	0	100	-0.1	0
7	0	-10	100	0	+0.1
8	0	+10	300	0	-0.1

d X0, dY0 = difference of camera position
reference = photo 1

table 1: configuration of photos for calibration

	lens 2050	SNR	lens 53203	SNR
ck (mm)	72.209		72.887	
dx0 (mm)	0.037	6.9	0.4416E-6	0.9
dy0 (mm)	0.008	0.9	-0.1292E-4	2.0
a1	0.5326E-1	0.9	-0.4287E-1	0.5
a2	-0.7984E-5	0.2	0.2404E-4	0.2
a3	-0.1036E-5	1.8	-0.2768E-6	0.3
dck	0.7195E-9	0.2E-4	0.2201E-9	0.5E-5

SNR = adjusted value / standard deviaton

table 2: results of calibration for both cameras

Determination of control points

As mentioned above at the fixing of control points restrictions had to be obeyed. Therefore, for each part of a stone 6 control points were fastened (s. fig. 4): screws with a diameter of 5 mm and length of 5 cm. They were inserted in borings and fixed by a specific adhesive. The coordinates of control points were determined photogrametically: spatial distances were measured (s. fig. 4) and three photos were taken. Two of these photos are in accordance with the stereo normal case and serve also for the survey of the stone surfaces (s. fig. 5). A self constructed tool was used to measure the distances within the range of acuuracy of 0.1-0.2 mm.

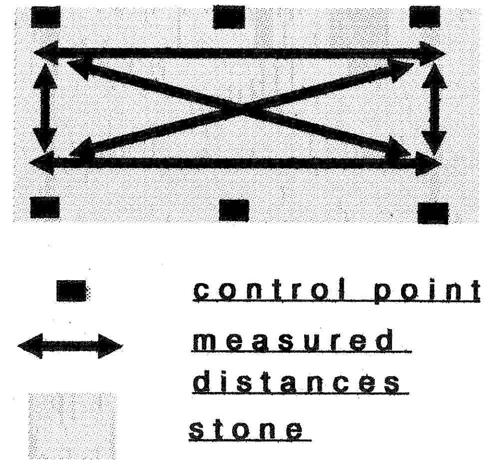

figure 4: configuration of control points and measured distances

The following bundle block adjustment was evaluated as a free spatial net and the measured spatial distances introduced with a standard deviation a priori of 0.1 mm */Düppe 1984/*. In fig. 6-7 and tab. 3 the standard deviations of control points and the residuals of the distances are sumed up for the six parts of stones. One can see that the required accuracy - especially for Z-coordinates - was achieved.

The survey in the second epoche requires a check of stability of the fixed control points. There a strategy respective to */Pelzer 1985/* will be applied. In order to guard against the loss of control points by changing of their position compared with epoche one additional signals will be attached to the stones during the measuring campaign. Afterwards they will be removed. This work will be done in the near future. The results of the comparison will be presented in a poster session in Washington.

STRATEGY OF DATA COLLECTION AND REPRESENTATION

Preliminary considerations

Before evaluating stereo models for the purpose of surface modelling some basiç considerations are useful. They refer to the accuracy and quality of digital elevation models (DEM) derived of measuring a regular grid, the kind of data collection and the realisation of the comparison.

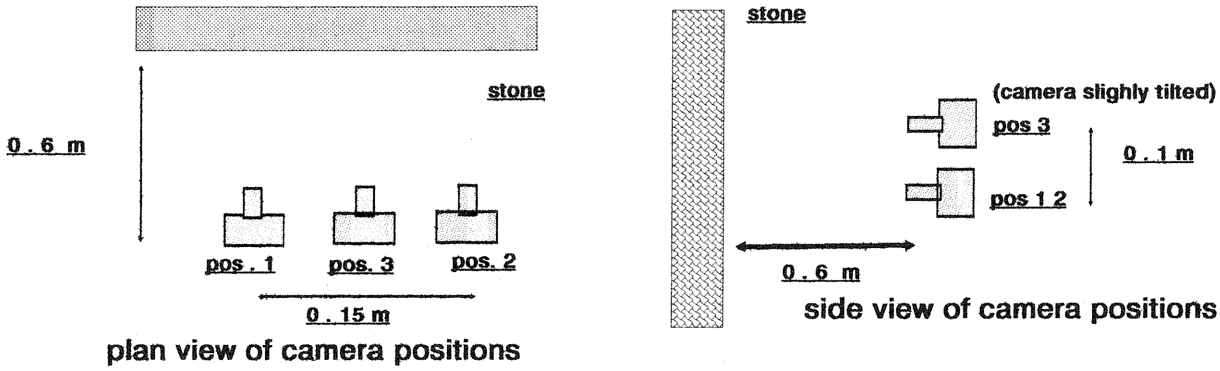

figure 5: configuration of cameras: left plan-, right side view

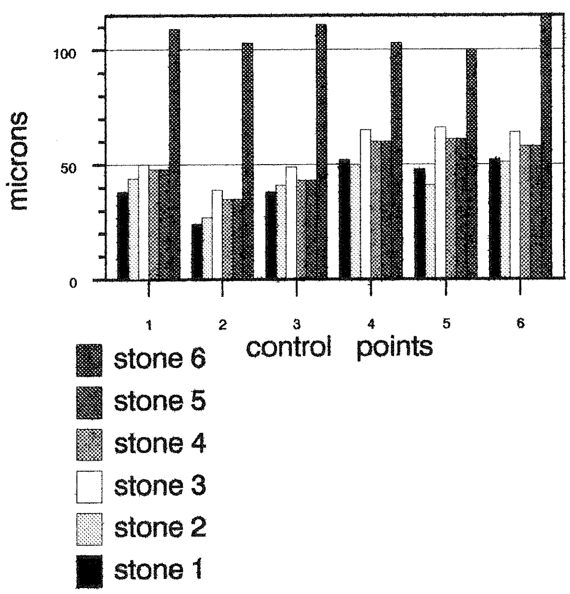

figure 6: standard deviations of control points in X/Y

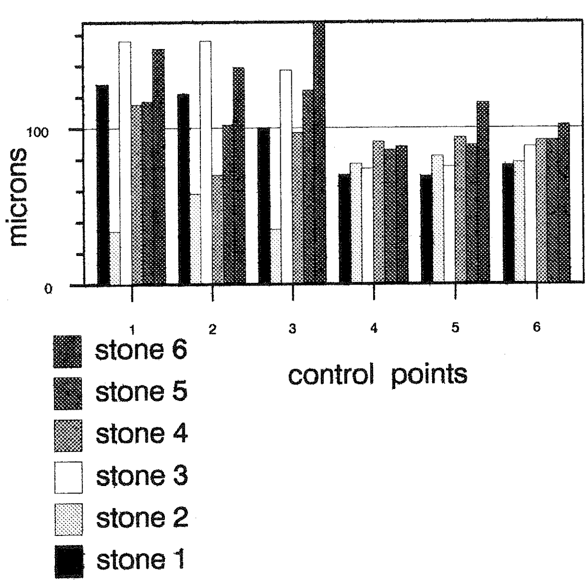

figure 7: standard deviations of control points in Z

distance	stone 1	stone 2	stone 3	stone 4	stone 5	stone 6
1	-72	55	-63	96	65	-74
2	-37	-82	47	-79	-67	84
3	11	45	81	-82	24	-54
4	-72	6	-50	-81	-19	-27
5	26	40	-4	54	-77	58
6	84	-56	11	34	96	36

unit = microns

table 3: residuals of the introduced distances

	sXY (micron)	sZ (micron)
Model 1	27	38
Model 2	42	32
Model 3	21	21

table 4: residuals of 3 oriented models

In */Reinhardt 1991/* the most important requirements to a DEM are performed (s. chapter 5). They concern

the average accuracy of any point of a DEM,

the accuracy of slope and curvature,

the detection of gross errors,

the completeness of morphological features and

the fidelity and reproduction of characteristic topographic shapes.

The geometrical accuracy can be described by the following criteria as shown in */Balce 1987/* (error propagation): accuracy of the control points (s_{AT}) after block adjustment, the residuals after having fitted a model (s_{MOD}) and the expected accuracy (correlated e.g. with the flying heigth in aerial photogrammetry (s_{MEAS})).

$$s^2_{GRIDPOINT}=s^2_{AT}+s^2_{MOD}+s^2_{MEAS} \qquad (1)$$

Set s_{AT} = 0.1 mm, s_{MOD} = 0.04 mm (s. tab. 4) and s_{MEAS} = 0.06 mm (i.e. 0.1% of distance to the object) you get a $s_{GRIDPOINT}$ of 0.123 mm. So it is within the required accuracy range.

The topics completeness of morphological details and the fidelity of characteristic shapes essentially depend on the sampling rate and the quality of data collection. According to the formula (s. */Kraus 1985/*) kind and size of details are the most important factors for the correct choice of the minimal sampling rate (compare formula (2)). Figure 8 sumes up some mesh sizes due to radius of details which are characteristic for the natural stones of Limburg monastery.

$$DX = \sqrt{8 * s_{GRIDPOINT} * DR_{DETAIL}} \quad (2)$$

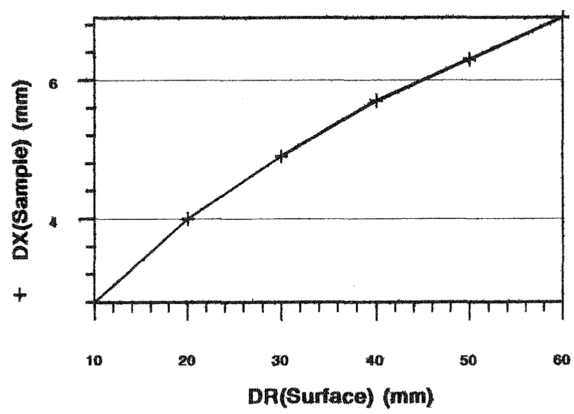

figure 8: variation of sampling rate DX as a function of radius of details DR

For the comparison of two data sets it is necessary to know if all topics mentioned above are to be taken into account. It is clear that the accuracy of the control points and the detection of gross errors are important. Aspects refering to morphological details and fidelity of characteristic shapes are not so important if the comparison is not realised using for each epoche. It means that the differences are evaluated diretly at the gridpoints.

Strategy for measurement and a first example

Because statements about quality and reliability of interpolated DEMs either empirically using references or with analytical methods (compare */Reinhardt 1991/*) can be made. On the other hand in our case two data sets have two be compared and the expenditure has to be as low as possible. Therefore, the following strategy was developed in correspondance with the participants:

representation of an entire surface only for visualization

direct comparison of the differences of the gridpoints represented by single profiles

subdivision of one surface in - if necessary - more sampling areas (comparable a progressive sampling) where the densitiy of sampling rate varies,

repetitive measuring of some profiles per model to get an idea about the individual accuracy of the operator.

The chosen strategy has the advantage that the accuracy of the differences depend only on the variables introduced in formula (1). Influences caused by the interpolation of an DEM are avoided. In figure 9 an example for a small area of a surface of a natural stone is depicted (compare also fig. 2, right). The measurement was carried out on an analytical plotter P3 (Fa. ZEISS), mesh size 3 mm, number of gridpoint = 243. The small ditches are clearly visible.

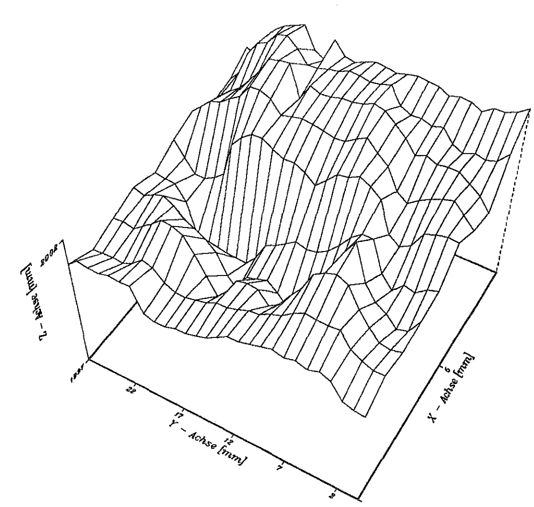

figure 9: visualization of a small part of a surface of a natural stone containing a ditch

A further aspect for surveying of surfaces of natural stones is given by the fact that the stones have low contrasts by itself. In order to support the quality of measurement the photos were taken with an artificial light source (spot-light). The surface was lighted from upper left and it was yielded an effect like hatching. This procedure has the advantage that the operator gets an very three-dimensional view instead of the small differences in elevation on the surface.

CONCLUSION AND OUTLOOK

Although the results can not be presented in its entirety in this paper it could be shown that with a relatively small effort the reconstruction of a surface of a natural stone with an high accuracy can be realised. Because the account of the weathering process is not a priori known, an approach passing into macro-photogrammetry as described in */Mauelshagen, Strackenbrock 1990/* would have been more suitable. The resolution which can be achieved in that way - in the range of some microns - is in better accordance with the structure of a natural stone.

Regarding the developments in the area of digital photogrammetry relying on surface reconstruction for a close-range application like this one new perspectives are given. Taking digitized photos or using a CCD-camera it is also possible to meet the task. At our institute a first attempt will be made. Then the surface reconstruction will be evaluated with Facet Stereo Vision (FAST Vision), an approach introduced by Prof. Wrobel */Wrobel 1987/*. In the future more and more automazation of the measuring process will be achieved. This offers the curators of monuments a photogrammetric tool which enables a quick interfering if stones are threatened by weathering of stones.

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