

## LOW-COST IMAGE BASED SYSTEM FOR NON-TECHNICAL EXPERTS IN CULTURAL HERITAGE DOCUMENTATION AND ANALYSIS

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### ABSTRACT:

As it is widely known documentation is an important issue within the tasks of conservation, preservation and restoration of Cultural Heritage objects. In this context high-tech measuring methods which, at the same time, are located in the low-cost price segment, are of special interest. In this paper a special solution is presented, which preserves the potential of state-of-the-art photogrammetry and is simple enough to be used by non-technical experts on their own. The design of the system enables, e.g., scientists of the humanities to benefit from modern 3D measuring methods in their daily work without needing permanent support by technical professionals. The system consists of off-the-shelf digital cameras which actually have reached a high level of resolution, of image quality and of functionality, all at a reasonable price. Ease of use for measuring purposes is guaranteed by mounting one or two cameras on a specially developed space bar. The corresponding evaluation software allows for stereo-viewing on standard PC hardware, for various methods of stereophotogrammetric model referencing, for object digitizing as vector features, for data export as CAD data, for production of orthophotos and of true-scale object representations of curved surfaces. Two projects are reported for illustration of the system's application. The first project deals with the documentation of 500 caves in the Ukrainian area of Crimea, the second one gives an example for the application in the field of preservation of historical monuments in Germany. In both projects the stereophotogrammetric system was used as an integrated part within the full spectrum of modern metrology methods, comprising laser scanning, tacheometry, GPS and more.

### 1. INTRODUCTION / MOTIVATION

Documentation is an important issue within the tasks of conservation, preservation and restoration of Cultural Heritage objects. As an example, UNESCO forces the documentation of World Cultural Heritage with the most advanced techniques. Even in the year 1972 the UNESCO Convention concerning the protection of the world cultural and natural heritage (UNESCO, 1972) already required that, international assistance on a large scale shall be preceded by detailed scientific, economic and technical studies. These studies shall draw upon the most advanced techniques for the protection, conservation, presentation and rehabilitation of the natural and cultural heritage' (UNESCO, 1972, see article 24). Recently, the World Heritage Committee encouraged its member states ,to integrate concern for World Heritage into wider national disaster reduction plans and documentation programmes' (UNESCO, 2006). Consequently, organisations like the International Society of Photogrammetry and Remote Sensing foster, e.g., technical developments in the field of Cultural Heritage documentation like the development of low-cost and rapid techniques in documentation and monitoring of the cultural heritage (ISPRS, 2007).

Nowadays, the spectrum of modern metrology provides for a wide variety of measuring methods, each of it with specific properties concerning accuracy, usability, needed user efforts, type of results and so on. This means, that various measuring methods can be used to record the spatial and visual properties of cultural heritage objects. The capabilities of different types of measuring devices are different. That is why the two aspects of spatial and visual as well as textural description often can not

be fulfilled by one single type of equipment in the same way. On the other hand, dependent on the application one of both aspects is of higher importance and thus influences the method or tool to be used. Trying to create integrated results containing both type of information, spatial and visual, can be hard, either in terms of additional post-processing work to be done after recording data or in terms of hardware which must be available to meet such tasks. The price of high quality sensors like special photogrammetric cameras or 3D scanners is often very high and not affordable in each type of project. In addition, processing of photogrammetric data might be hard for non specialised users.

At the moment only photogrammetric solutions have enough potential to extract spatial and textural information at the same time. Such methods, therefore, are of particular interest in cases, where a maximum of base information is needed for subsequent analysis steps. However, typical photogrammetric equipment is made for use by specialists with sufficient knowledge in the use of advanced surveying techniques. So, it's hard for an end user to handle this technical equipment, because he simply desires to analyse the object from an application-specific view point, but is not trained as photogrammetric operator. On the other hand, technicians normally do not have much ability to interpret and analyse the object from the view of an application. One common way to solve this problem is a clear definition of requirements which has to be agreed between both parties.

Beyond that in many cases it might be desirable to find other solutions in order to keep costs low, to gain more flexibility or for other reasons. In this context, a solution, which preserves the potential of photogrammetry and, at the same time, is

simple enough to be used by non-technical experts on their own can be very helpful. In the following sections a complete system consisting of all hardware and software components suited to document the spatial and visual properties of cultural heritage objects will be described. Two case studies will show which process steps have to be passed in practice to achieve appropriate results.

## 2. DIGITAL STEREO EVALUATION STATION - DISTA

Nowadays from the technical point of view off-the-shelf digital camera systems together with conventional PC-equipment are sufficient to perform many photogrammetric tasks (Drap 2001, Hence et. al. 2006, Pomaska 2001). Even stereo viewing is no longer a problem and is possible with different technical solutions. Digital cameras have undergone big improvements in the last years with regard to resolution and image quality. Digital SLR cameras are available for a reasonable price. When digital cameras are mounted on a space bar of variable length stereo-models can be simply recorded.

Important points determining the usability of these techniques are structure and complexity of the work flow and the software existing for the individual steps together with efficient, affordable and simple to use camera equipment. It is necessary to have software being easy to use by application scientists and it has to run on standard hardware. Only then this technique will be accepted by non technical end user allowing to widely introduce photogrammetric solutions in the appropriate field of application.

### 2.1 Hardware

At the very beginning of an evaluation process images have to be taken. This is one of the key steps, determining the complexity of the following steps and, in addition, being responsible for efficiency and accuracy. As non photogrammetrists often don't know about risks involved in this action, results easily tend to be error prone. A simplification of this initial act therefore will reduce handling problems and assure at the same time a certain quality of the spatial content in the images.

This simplification is ensured using a fixed stereo base forcing the user to provide useful photogrammetric conditions in the image data to be taken. Digital SLR-cameras can be mounted at varying positions on a space bar allowing to adopt the configuration to the needs of the size of the object assuring an appropriate base to distance ratio. The stereo base can be mounted on different tripods and might be used as single or two-camera-system. The system's setup for single-camera application is realised as shown in Figure 1.

Different SLR cameras can be adapted with special attachments onto the space bar which makes the system more flexible for varying geometry configurations (cf. Figure 2).

Several aspects influenced the construction of the space bar. Besides simpleness of construction and low-cost of the components, low weight, intuitive handling and solidity were considered. Dimension is a critical point because the system is used for archaeological documentation abroad and, therefore, frequently has to be air-shipped.

Constructional effort assuring optimal parallelism of the optical camera axes can be kept within limits due to an automated

relative orientation approach allowing to calculate the true orientation without large interaction of the user. So, correct photogrammetric functionality is assured without special knowledge of the user and without largely investing into the technical equipment.



Figure 1. Single-camera-system with space bar

The designed more or less fixed stereo configuration could be seen as a limitation factor and as being not flexible enough, but it avoids problems for an end user being not familiar with the rules of photogrammetry. And this is of great importance as long-term experiences with non-technical users have shown. The lack of photogrammetric knowledge often ends up in an inappropriate selection of the view points for the cameras resulting in unreliable geometrical constellations with corresponding wrong spatial data.

### 2.2 Software

With respect to the software components all standard processing tasks are supported. The software runs on standard PC hardware. On simple computers stereo-viewing in anaglyph mode has to be used, shutter glasses are supported when a 3D graphics card is available. Tiled images with pyramid layers are used in the system, allowing high performance even for high resolution images (e.g. scanned analogue images).



Figure 2. Attachment of SLR-camera to space bar

Various mathematical set ups can be chosen to model the camera geometry, what allows to adapt the configuration to the requirements of the users. When several models are needed, they have to be put into a common framework by means of

reference points. In case of individual models the orientation can be simply performed by introducing a scale coming from a reference distance, measured in the object space.

Object geometries can be digitized in the georeferenced photogrammetric 3D models as vector features and exported in CAD format. Supported data types are points, lines, polygons or other geometric primitives.

The high information content of the image data is primarily important for the process of evaluation but can be additionally useful to generate products like orthoimages. They provide high resolution textural information in a correct two dimensional context.

Draping the textural information onto cylindrically or conically shaped object parts is another option of the solution. This feature enables the user to create unwinded object representations for curved surfaces at a uniform scale.

The step of relative orientation of two images can be performed conventionally or by means of an automatic process which is based on image matching. The automatic process can be supported by a simple estimation of the base to distance ratio. Even a very rough estimate makes the orientation more robust, because such a prior knowledge shrinks search spaces and reduces the risk of wrong correspondences.

The approach is based on image pyramids through which the calculation steps from coarse to fine resolution. Each pyramid level provides an orientation which serves as input for the next finer level. In general, three steps are sufficient to end up in a final orientation.

Within each pyramid level the orientation points are found by means of an area based technique. This has the advantage to work even with lower contrast and allows to control the distribution of the points within the overlap region. Problems may arise in case of steep edges or other strong curvature variations in the object due to the perspective impact onto the images.

In such cases a feature based matching method is superior. This will be implemented in later development steps. It will be advantageous in case of ragged objects captured with large image scales. Draw back of a feature based strategy is a potential correlation of the point distribution to the spatial structure of the object. Feature points are linked to strong contrast variations with naturally will occur in regions of spatial roughness. Therefore the distribution of orientation points tends to be clustered and non-uniform, what may reduce the geometrical quality. Therefore a final solution will use both strategies in a balanced manner.

As known from the functionality of analytical plotter a known relative orientation can be taken to support the user during the evaluation of the model. The superimposition of the images in the viewer produce vertical parallaxes as soon as the optical axes of the images are not parallel. During evaluation this parallax is permanently corrected in order to disburden the user from doing it interactively.. More input aids are given by navigating in the model with common input devices which can control zoom factor and x-parallax for height measurements.

## Workflow

In the following a description of a typical workflow when setting up a DISTA project is given. Furthermore, basic functionality to digitize contours within a stereo model is shown.

Before an object can be evaluated stereo images of the object have to be taken from the stereo base. The interior orientation parameters of the cameras have to be known from a previous system calibration process.

As the program only uses tiled images in order to speed up the image access during measuring processes the images first have to be transformed in such a data structure. This is the first step, which has to be realised before a new project can be initialised. After creating a new working environment, the necessary orientation steps have to be performed. The results of every orientation step can be stored for later assessment and comparison.

Restoring the interior orientation parameters is not always mandatory. For digital images it can be skipped as the physical position of the image sensor should remain stable within the camera system and the parameter which once have been determined can be used for a longer period of time. If metric analogue cameras, e.g. medium format cameras, are used the interior orientation has to be restored by measuring the fiducial marks in the digitised image material.

Relative orientation can either be performed conventionally by measuring a certain number of tie points or can be done automatically as described in the previous chapter. To perform relative orientation, within a set of measuring windows the operator is prompted to measure object points of appropriate distribution as shown in Figure 3.

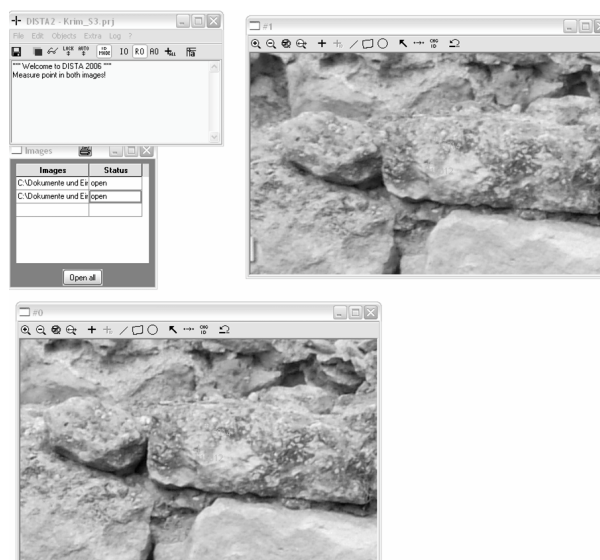


Figure 3. DISTA - window setup for relative orientation

Results of a relative orientation as obtained from the evaluation software are shown in figure 4.

With a successful relative orientation the user is able to perform spatial measurements. If there is no reference system which has to be considered, the measurement of a single object distance allows to introduce the true scale providing a fast way for

absolute orientation. In most cases ground control points will be used giving the relation to the object system. Given control points, measurements for orientation and evaluation results are logged in an object points table.

```
Results Relative Orientation:
-----
P O K left:    0.034977 0.000000 0.008139
P O K right:  0.028108 -0.004578 0.002554
Sigma:        0.000319
Svx:          0.004717
Left:         Svx=0.000025 Svy=0.003333
Right:        Svx=0.000015 Svy=0.003333

Rotation matrix left:
0.999355 -0.008134 0.034970
0.008139 0.999967 0.000000
-0.034969 0.000285 0.999388

Rotation matrix right:
0.999601 -0.002681 0.028104
0.002554 0.999986 0.004578
-0.028116 -0.004504 0.999595
```

Figure 4. Protocol of relative orientation

After completing the orientation steps the user is enabled to perform digitalisations of the recorded objects directly as CAD data which also can be edited in a second step. For this purpose, anaglyph and shutter modes are available. Digitalisation of points, lines, polygons and other geometric primitives is supported. Each measurement is recorded in an object points table and plotted into the field of view during measurement for completeness control (cf. figure 5).

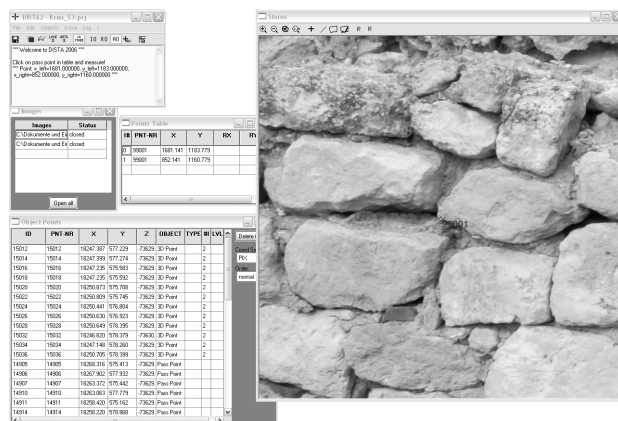


Figure 5. DISTA - window setup for digitising in shutter mode

With the help of a software interface DISTA might be used even as a 3D input device in CAD environments (e.g. AutoCAD), if more complex object structures have to be evaluated.

### 2.3 Accuracy consideration

Depending on image material, camera geometry, image scale, base to distance ratio and evaluation hardware, different levels of accuracy can be obtained. Comparing the DISTA solution with usual photogrammetric equipment like stereo plotters gives a reliable impression of the resulting orientation and evaluation quality. A test was performed with analogue medium format images taken from the metric camera ROLLEI 6008 metric

which were used for usual photogrammetric evaluation in a stereo plotter. The digital image material was derived from a conventional digital SLR camera (FUJI S3). Both cameras were used on a stereo base bar for image capturing.

Residuals of absolute orientation			
Nr.	[m]		
	rX	rY	rZ
Stereo Plotter (image scale 1:150)			
1	0,0050	0,0030	-0,0055
2	-0,0009	0,0022	0,0082
3	-0,0043	-0,0020	0,0040
4	-0,0049	0,0021	-0,0046
5	0,0043	-0,0046	-0,0001
DISTA (image scale: 1:300)			
1	-0,0146	-0,0064	0,0069
2	-0,0009	-0,0091	-0,0015
3	-0,0022	0,0094	0,0004
4	0,0024	0,0077	-0,0034
5	0,0004	-0,004	0,0022

Table 1. Comparison of absolute orientation results

The results of absolute orientation are shown in Table 1. The numbers prove good comparability of the image evaluation with stereo plotters and with DISTA. The given residuals are in the same order of magnitude which indicates that both systems are able to deliver their results in the same range of geometric quality, in this case in the sub-centimetre range.

## 3. PROJECTS

Applications where the new system yields remarkable profit were identified in the field of preservation of historical monuments. In cases, where control points are measured, the stereo models taken on site can easily be used to capture additional metric features in later processing stages. Temporally delayed data processing as a requirement often occurs in the field of preservation of historical monuments and was proved to be accomplished during the recording of several monuments. Here again, the high potential of image based representation by stereo-photogrammetric methods was shown.

As in many other fields, the question, how photogrammetric measurements fit into the full spectrum of modern metrology containing methods like laser scanning and fringe pattern projection, has to be answered also in the application field of monument documentation. To illustrate how the photogrammetric system intertwines with other methods its application will be described in another project. Besides laser scanning and fringe pattern projection, our photogrammetric system here was applied to quickly produce high resolution stereoscopic views of the historic site supporting historians' work.

### 3.1 Crimea, Ukraine

Within a project at Roman-Germanic Central Museum in Mainz, Germany in cooperation with the Ukrainian Academy of Sciences, the University of Simferopol, Crimea, and other partners, a large number of about 500 caves from early medieval times cut into the limestone rock have to be documented.



As the complete three dimensional detailed recording of all objects is neither possible in the given time nor necessary, the geometrical documentation is carried out with different techniques and varying levels of details.

3D laser scanning is affordable only for a reduced number of selected caves. For appropriate objects and situations terrestrial 3D laser scanning is used to record complex geometries as a basis for measurements and basic visualisation of the scene.

A number of caves being representative for different types of construction, complexity, size and usage are recorded in detail using reflectorless total stations. The total station is used to measure single objects identified on-site. Every single object cut into the stone within the caves and outside of them which is visible is recorded as a detailed basis for reconstructions of usage and dating.

Selected horizontal and vertical sections complete the base data for generating plans and maps for printed publications. Additional caves of simple shape without additional features or decoration are recorded by their position, few numbers concerning size and aspect and additional textual description. Photos, and much more stereo-models, give additional information of the object to be examined at any time in the office.

Taking stereo images is an additional method to record texture and geometrical information of the caves. The data is used on the one hand for viewing the recorded situation in three dimensions later. Additionally geometric information in form of points, lines and polygons can be extracted from the photogrammetric data. In case of very simple objects, the stereo images are taken without external control points. A ruler, levelling bar or similar device is recorded to introduce a scale into the stereo model or the scale information can be taken from the base length after orienting one model using control points.

The higher level of details for recording is the combination of few total station measurements to get horizontal and vertical sections plus control points for the stereo images. Geometrical information from the model is only extracted if necessary for the further process.



Figure 6. Image capturing from space bar

Using the described stereo base eases the recording of the images distinctly. Almost parallel directions for both camera orientations are ensured by the mounting adapters on the base. The length of the basis is adopted dependant on the mean

distance between camera and object and a reasonable basis to height ratio. For the described objects a ratio between 1 : 5 and 1 : 10 ensures good stereo impression for viewing and measuring. Figure 6 shows the application of photogrammetric work on site. In Figure 7 an evaluation result can be seen.

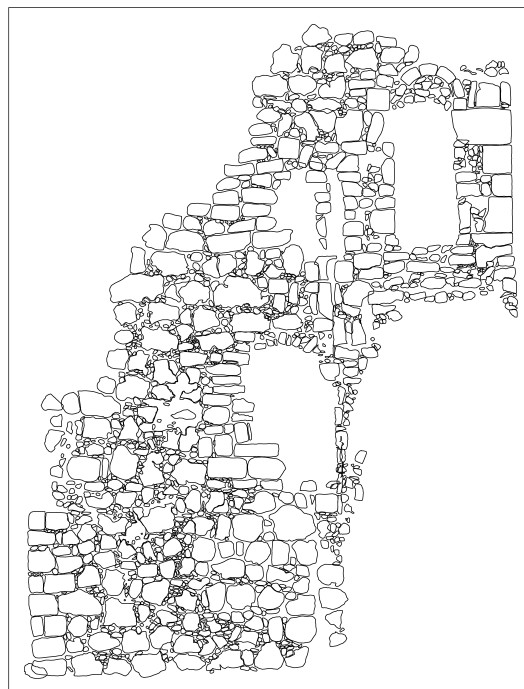


Figure 7. Contour lines digitised with DISTA

A problem for the image quality for these objects may be big differences in brightness between darker wall areas and windows, respectively holes in the caves. This may lead to under- or overexposed areas within one image. A solution for this can be the generation of high-dynamic-range images. Several images e.g. 3 are taken with varying exposure times. Many modern digital reflex cameras support this option directly in bracketing mode. These images are combined together and reduced to a low-dynamic-range image (8 bit per channel) showing objects in all parts of the image with recognisable brightness. These images lack natural representation but improve the visibility of structures.

### 3.2 Porta Nigra, Germany

At Porta Nigra in Trier, Germany (see Figure 8) the task of surveyors was to support the work of historians to investigate the building's history. The main focus in this project was to document geometry and position of the precise sandstone blocks which were used as building material. Therefore various measuring methods were tested to record the distribution of the accurate joints at the buildings' surface. It turned out, that popular measuring techniques like 3D laser scanning and tacheometry were not useful to solve this problem.

Tacheometry holds a big potential of high accuracy for single evaluated points at the object's surface. For economic reasons on the other hand this method gets rapidly unattractive. For that reason total stations were used only to observe geodetic networks and to support laser scanning and photogrammetry by providing for highly accurate control points.

3D laser scanning covers the recorded object by millions of points and gives good visual impression and a digital reproduction of even complex and structured surfaces. Nevertheless, edge effects and noise of range measurements downgrade the usage for the intended purpose as joints in the point clouds did not appear in a usable way.



Figure 8. The Porta Nigra, Trier / Germany, UNESCO World Heritage Site

In addition, stereo photogrammetry was tested during the project at a section of the Porta Nigra. The evaluation of the image material was done with the DISTA application whereas some exemplary contour plans were evaluated (see Figure 8).

It was reflected that photogrammetry is the most suitable technique to produce base maps for the work of historians. The desired procedure is to produce basic contour maps which can be completed and refined by specialised scientists by evaluation directly at the object's surface from scaffolding.

#### 4. CONCLUSIONS

Recently, the development of digital camera systems available at the broad consumer market experienced remarkable big steps ahead. Cost-efficient PC hardware nowadays provides for considerably improved 3D processing capabilities. All this made it possible to develop a low-cost system which still maintains the high-quality potential as inherent to photogrammetric systems.

Besides cost-effectiveness, the main goal when developing the system was to guarantee its usability for non-technical experts. Prototypes of the system were tested extensively in various application fields of the humanities. The results of the tests were used to improve both the system's hardware and software components to make it meet those users requirements as best as possible.

The results as obtained so far lead to the conclusion that the stereo-camera in combination with the easy-to-use software is a very good tool to support the documentation of cultural heritage objects in a very flexible way. The software allows to reach different levels of geometric accuracy according to technical resources and professional requirements. Continuous application of the system in current and future projects will help to tune the system further on according to the needs of, particularly, non-technical users.

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