

APPLICATION OF A NEW MODEL HELICOPTER SYSTEM IN ARCHITECTURAL PHOTOGRAMMETRY

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ABSTRACT

In architectural photogrammetry the production of facade plans or 3D models is usually one of the most important points of interest. The disregard of roofs is partly caused by the lack of appropriate image acquisition methods. In order to overcome these drawback a new image acquisition system has been developed. This aerial vehicle consists of a radio controlled model helicopter including a special designed camera mount which is an integrated part of the landing skid. The camera mount is designed for amateur cameras as well as for professional cameras and for digital video cameras and can be tilted radio controlled. In addition, a separate small CCD-Camera looking through the view finder and a video link including video transmitter, video receiver and ground-monitor are used to provide an in-flight control of image contents and to control the shutter release. In order to check the applicability of the helicopter for photogrammetric purposes, a historical mill was chosen as a test object. The mill itself is a rather complex building with an inner courtyard. For this pilot project 82 terrestrial photographs, taken with a digital camera, were combined with 38 photographs taken from the model helicopter. The photogrammetric measurements were made using the new photogrammetric plotting software ORPHEUS. This paper describes the application of the new helicopter system for architectural photogrammetry and the production of a high-quality 3D photo model. Special emphasis is laid on the description of the new helicopter platform and the software used for photogrammetric plotting.

1 INTRODUCTION

In architectural photogrammetry the production of facade plans is usually one of the most important points of interest. The disregard of roofs is partly caused by the lack of appropriate image acquisition methods. Using a crane or a hydraulic jack is often to cost expensive and the resolution of aerial photographs often does not fit the requirements because of safety restrictions of flying height. Similar problems appear in the field of archaeological excavations. The use of radio controlled model helicopters and zeppelins seems to provide a solution for these problems. However, there are also problems connected with these platforms. The shutter release is also radio controlled and usually the contents of the taken photograph is only approximately known. In addition, professional helicopter systems are often too expensive. That is why these systems have only been used scarcely, too.

In order to overcome these drawbacks a new image acquisition system has been developed. This aerial vehicle consists of a radio controlled model helicopter including a special designed camera mount which is an integrated part of the landing skid. In addition, a separate small CCD-Camera and a video link including video transmitter, video receiver and ground-monitor are used. The model helicopter needs only a small space for starting and landing and is able to hover over one spot. It can be applied for all types of close range projects including industrial applications.

In order to check the applicability of the helicopter for photogrammetric purposes, a historical mill was chosen as a test object. About 80 terrestrial photographs were taken of the mill which is a rather complex building with an inner courtyard. For that purpose a digital camera (Kodak DCS460c) with two different focal lengths was used (15 mm and 28 mm). In addition, 38 photographs using a small format amateur camera were taken from the model helicopter recording the roof scenery. Control information was provided by geodetic measurement of about 120 distinct points. After scanning the helicopter images a 3D model of the mill was produced using a photogrammetric engineering utility system (ORPHEUS) developed at our institute.

In this paper, the new helicopter system will be described in detail in section 2. Section 3 deals with the project setup and the field work which was required for that project. The process of photogrammetric measurement and hybrid adjustment for orientation purposes as well as the process of modellisation is described in section 4, where special emphasis is laid on the new photogrammetric plotting software ORPHEUS. Finally, in section 5 we want to show how the 3D model can be visualised using the data format VRML (Virtual Reality Modeling Language).

2 THE MODEL HELICOPTER

The new image acquisition system consists of a remote controlled helicopter and a handheld ground unit. The helicopter is designed to carry various sensors such as photographic and video-cameras, air pollution detectors and other devices. Only a few square metres are required for starting and landing the helicopter, and it can hover over one spot. It is able to fly in areas where full size helicopters are too big or where they must not operate. Such an area is for example near to ground between 20 m and 150 m flying height. However, operating in this area gives the best results for many close range and industrial applications. In addition the operation of full size helicopters or planes is much more expensive.

The helicopter is built of robust, lightweight and high strength-materials. A two-stroke petrol engine propels the main- and tail-rotor. The fuel capacity enables a flight endurance of 20 minutes. A trained model helicopter pilot controls the Helicopter via radio control unit. The mission radius, which is the distance between the pilot on the ground and the Helicopter is up to 300 meters, depending on the necessary flight accuracy. Note that for a safe flight the helicopter has to be constantly visible by the pilot. Thus, there must not be any obstacles in the line of sight.

A specially designed camera mount is an integrated part of the landing skid of the helicopter. The camera mount is designed for amateur cameras as well for professional cameras (format size of up to 6 cm by 6 cm) and for digital video cameras. The camera mount can be tilted by radio control. Specially designed dampers absorb all vibrations during flight and guarantee high quality pictures without motion blur. In addition, a separate CCD-Camera together with a real time video link including video transmitter, video receiver and ground-monitor are used for in-flight control of the image contents: The separate CCD-Video-Camera looks through the viewfinder of the photo camera, and the picture of this CCD-Video-Camera is transmitted by a real time video link to the ground monitor, where an operator controls the image. This image shows exactly what the viewfinder of the photo camera sees. Controlling this image the ground operator advises the pilot, who controls the flight route of the model helicopter.



Figure 1. The model helicopter

Technical data of the helicopter:

- Length: 1,3 meter
- Height: 0,8 meter
- Main rotor diameter: 1,8 meter
- Maximum payload weight (Camera): 5 kg
- Maximum operation radius: 300 meter (depends on flight conditions)
- Endurance: 20 minutes
- Typical applications: aerial photography, photogrammetry, environmental monitoring, surveillance and action movies

3 FIELD MEASUREMENTS

A historical mill situated in the town of Eggenburg in Lower Austria was chosen as a test object for the application of the new helicopter system. 82 terrestrial photographs were taken of the mill which is a rather complex building with an inner courtyard. For that purpose a digital camera (Kodak DCS460c) with two different focal lengths was used (15 mm and 28 mm). In addition, 38 photographs using a small format amateur camera were taken from the model helicopter recording the roof scenery. The helicopter photographs were also taken using two different objectives (37 mm and 48 mm). Figure 2 depicts the camera positions of the terrestrial and the helicopter images with respect to a ground plan of the mill.

Control information was provided by geodetic measurement of 120 distinct points. The greatest part of these points were determined by spatial intersection from a polygonal of 13 stations. Few control points could be determined by polar measurements. The control points which were in reach of the human operators were targeted using white adhesive

tape. In addition, well-defined natural points such as window corners or roof corners were used. The points on the roof were of special importance because they were necessary to connect the terrestrial and the helicopter photographs.

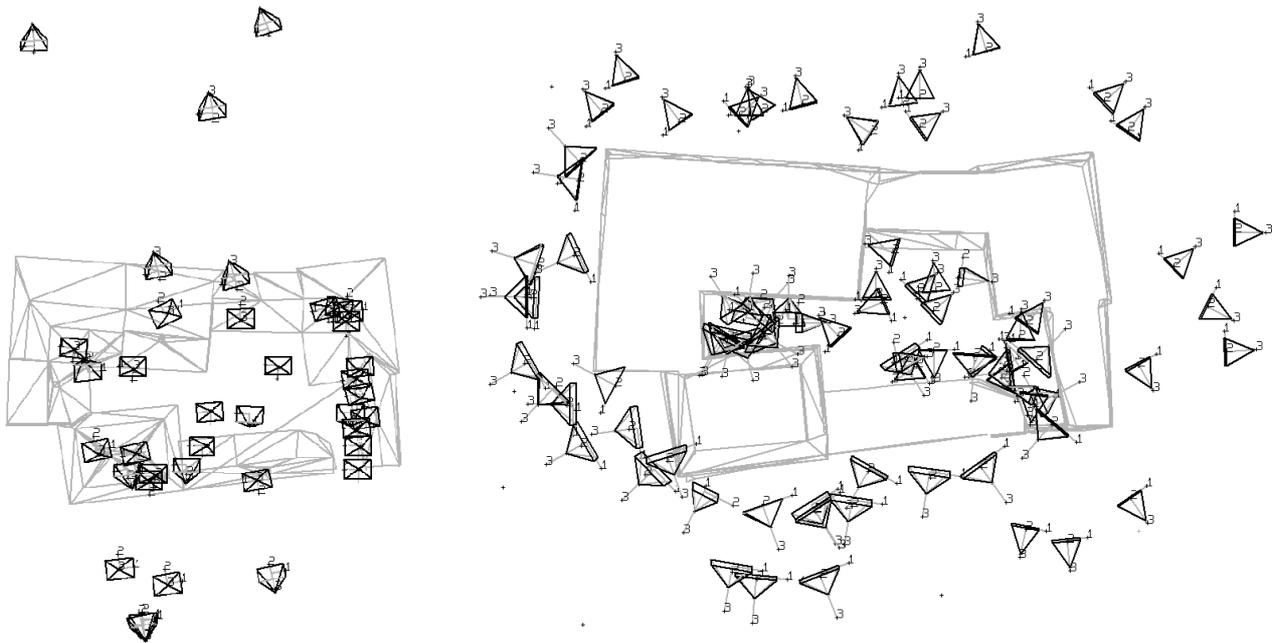


Figure 2. Configuration of the images: left: images taken from the helicopter; right: images taken using the DCS460c

4 PHOTO ORIENTATION AND OBJECT MODELING

Before starting with photogrammetric plotting, the helicopter photos had to be scanned at 15 μm . In order to produce a 3D model of the mill, the photos first have to be oriented. For that purpose, both control and tie points have to be measured in the digital images, and after that, hybrid adjustment has to be performed. As soon as the orientation parameters of the images are known, points relevant for modelling have to be measured and object lines describing the topography of the building have to be defined. This was done using the photogrammetric plotting software ORPHEUS (Kager H., Rottensteiner F., 2000).

4.1 ORPHEUS

The program **ORPHEUS** is a photogrammetric orientation and measurement software developed at our institute. This program provides the possibility of measuring points and/or lines simultaneously in an (in principle) arbitrary number of images (Figure 3). In addition, it offers a graphical user interface for the hybrid photogrammetric adjustment package **ORIENT** which has been developed at our institute since the mid-seventies. **ORIENT** offers the possibility of simultaneous hybrid least squares adjustment of many different types of observations, among others image co-ordinates, geodetical measurements, control points, model co-ordinates and fictitious observations of points belonging to polynomial surfaces and/or 3D curves (Kager H., 1989). In addition, **ORIENT** offers several techniques for blunder detection:

- Analysis of the distribution of residuals
- Iterative robust estimation by modulating weights depending on the residuals
- Data snooping

ORIENT is a very flexible tool for hybrid adjustment giving the user every freedom to parameterise the mathematical model of adjustment. With respect to photographs, it offers the possibility to model lens distortion by polynomial functions, which is of great importance in architectural photogrammetry in case non-metric cameras are used because the distortion effects would be clearly visible in the resulting 3D model.

The principle of measuring points in digital images using **ORPHEUS** is depicted in Figure 3: several images are visualised simultaneously on the screen. For each image, an overview as well as a zoom window is provided, the latter

being positioned by a click of the central mouse button. In the zoom window, bilinear resampling is used to display the image window so that it is possible to measure well-defined points with an accuracy better than 1 pixel. In addition, ORPHEUS offers image enhancing tools which can be locally applied to the zoom window only so that, for instance, contrast can be improved locally in dark image regions to render possible measurement.

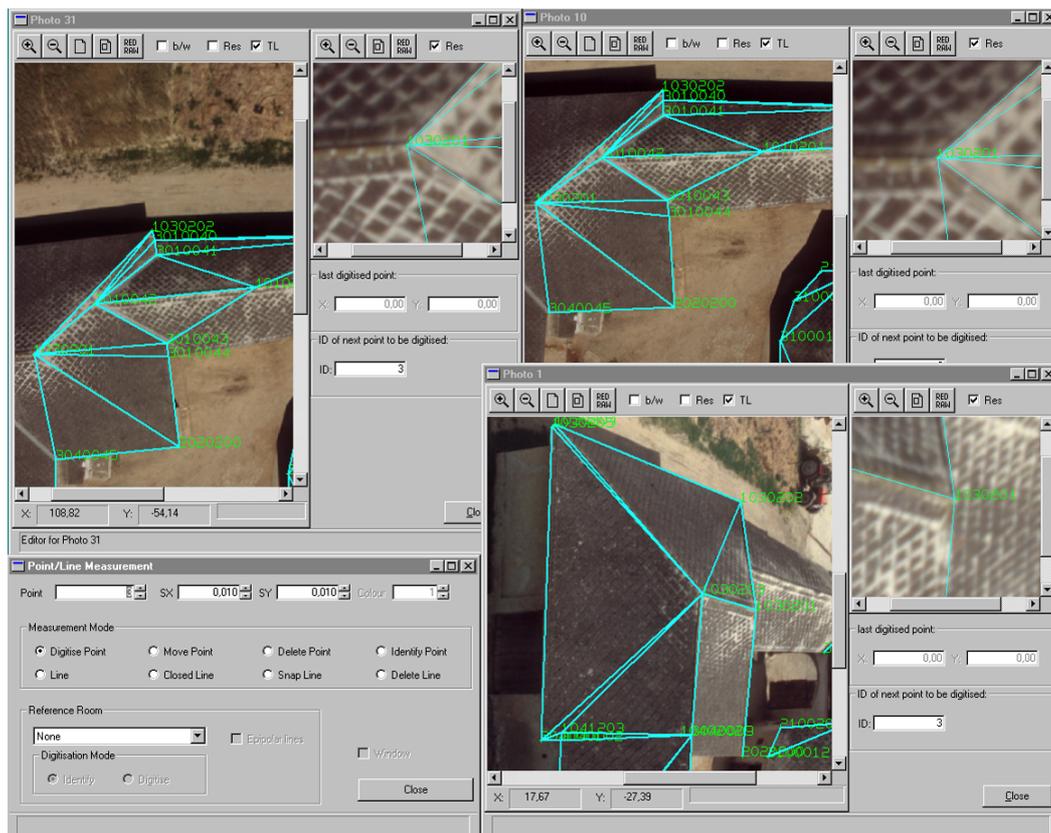


Figure 3. Interactive measurement of points and definition of lines using ORPHEUS

4.2 Photo orientation

The whole block was divided into two sub-blocks, one containing the geodetical observations and the terrestrially taken images, and the other one containing the helicopter images. The division became necessary because two groups of operators were involved in the work. The geodetically measured points as well as tie points in regions where not such points had been measured had to be identified in the digital images using ORPHEUS. The tie points had to be visible in at least three images to render possible blunder detection. First the sub-block containing the terrestrial images was worked out. As all objectives of the DCS460c had been calibrated in advance so that good approximations for the inner orientations of that sub-block were available. However, as the sensor was found out to be unstable with respect to the camera body and because enough measurements were available, on-the-job calibration was performed in order to improve camera calibration. With respect to the control points, the geodetical observations were adjusted simultaneously with the image co-ordinates, and only three points were actually treated as control points to define the local co-ordinate system in which the mill was reconstructed.

The second sub-block contained the helicopter images. As this sub-block was worked out after the terrestrial part, the results of terrestrial photogrammetry were used as control information. This means, that a part of the tie points of the terrestrial sub-block, especially those situated on the roofs, was considered to be control points here. The helicopter images were taken using two objectives, the focal lengths of which were only approximately. As these images were small format images scanned offline, in a first step a consistent system of reference for the inner orientation had to be provided in the images. For that purpose, the image corners were measured indirectly, these points were transformed to coarse approximate positions, and the transformed points were averaged so that these average transformed positions of the image co-ordinates could be used instead of fiducial marks. The accuracy of the averaged image co-ordinates was ± 0.03 mm which corresponds to ± 2 pixel. The co-ordinate system defined by the average image corners was considered to be the camera co-ordinate system to which the unknown inner orientation parameters and the distortion coefficients were to refer. After providing the camera co-ordinate system, measurement of both control and tie points was done in

exactly the same way as in the terrestrial sub-block. In hybrid adjustment, two sets of parameters of both inner orientation and distortion had to be determined on the job, one for each objective. With respect to the distortion coefficients, affine parameters and coefficients of a polynomial of degree 5 were determined (Kager, 1989).

Robust estimation was used to correct gross errors in both sub-blocks. After performing error detection, the residuals of the observations could be visualised by superimposing them to the digital images, and some of that errors were corrected, e.g. those caused by errors in the point numbers or by miss-interpretation of repeating image structures. In addition, an analysis of the variance components was performed to render possible. After that, robust hybrid adjustment was repeated, this time leading to the final versions of the orientation parameters. The results of adjustment for both sub-blocks are summarised in Table 1.

Block	FL [mm]	Pho	CP	TP	MP	s_{tie} [Pixel]	s_{model} [Pixel]	Obs.	Unkn.	Mark	s_{XY} [cm]	s_z [cm]
Terrest.	15	41	116	212	429	2	3	5443	2452	55	2	2
	28	41										
Roofs	37	32	284	36	299	1	2	3068	811	69	2	2
	48	6										

Table 1. Results of hybrid adjustment. FL: Focal length; Pho: Number of photos; CP: Number of control points; TP: Number of tie points; MP: Number of modelling points; s_{tie} : a priori r.m.s.e. of an observed image co-ordinate of both tie and control points; s_{model} : a priori r.m.s.e. of an observed image co-ordinate of the modelling points; Obs.: Number of observations; Unkn.: Number of unknowns; Mark: Number of marked observations; s_{XY} : average r.m.s.e. of the planimetric co-ordinates of the modelling points; s_z : average r.m.s.e. of the height of the modelling points.

4.3 Object modelling

After hybrid adjustment with self-calibration of the helicopter objectives, the modelling points had to be measured for both sub-blocks, and the topological information describing the surface patches of the 3D model had to be fixed. This topological information must be stored alongside the points identifiers and co-ordinates in the data set. Again, points were measured using ORPHEUS, but this time more emphasis was laid on the relevance of these points for modelling than on their exact definition, which results in the fact that often, poorly defined points had to be used which was considered by the stochastic model: the image co-ordinates of the modelling points were given a greater r.m.s. error (a smaller weight). These model points had to be connected by lines, which correspond to the object lines. As a result a wireframe model of the object was obtained. At that stage of modelling, the object has to be generalised. In order to generate a 3D photo-model the wireframe model had to be completed by additional lines dividing all object surfaces into triangles so that several conditions were fulfilled:

- The whole object has to be covered by the triangles (there must not be holes)
- These triangles thus must not intersect
- The triangles must be defined in a way that for each triangle there is at least one photo where all its corner points are visible.

If these conditions are fulfilled, an algorithm searching for closed loops in the wireframe model can automatically find the triangles. After measurement of the modelling points, their object co-ordinates had to be determined by spatial intersection. Again, gross error detection was applied as described in section 4.2. The accuracy of these points is little worse than the accuracy of the tie points due to the definition error of these points (Table 1). Again, modelling was done independently for both sub-blocks. In order to render possible an exact fit of the two model parts, care has to be taken to use identical points and to define topology in the same way along the intersection line. The geometrical model was converted to VRML (cf. Section 5) using ORPHEUS, and the resulting model was inspected with respect to its geometrical consistency. Several errors both in the measured points and in the definition of topology were corrected. After that, the textured 3D model of the mill was computed using the program PHOTOMOD developed at our institute. The final model consists of 703 triangles covering an area of more than 4000 m² with about 10 million texture elements of 5 x 5 cm². To improve visualisation the model has been put on an elevation grid (gridsize 5 x 5 m²) of the surroundings using an orthophoto as texture source.

5 VISUALISATION

For visualisation a 3D photo-model of the historical mill was computed and stored using the data format VRML. VRML is an acronym for "Virtual Reality Modeling Language". It is the international standard file format for

describing interactive 3D worlds and objects on the Internet (Carey R., Bell G., 1997). It is in fact the 3D analogy to HTML. This means that VRML serves as a simple, platform independent language for publishing 3D Web pages.

One of the main advantages of using VRML is that most VRML viewers are available free, so no additional costs arise for the viewing software. This format was also chosen because it enables a user-friendly interactive visualisation of the data, even via internet (<http://www.ipf.tuwien.ac.at/lehre/vrml/>). The user can interactively move around and examine the VRML scene. Of course some key-positions can be defined using viewpoints and then an automatic flight through the scene can be animated in real-time.

By using VRML additional information apart from geometry and texture can be linked to the 3D model. This information can be in the form of texts documents, sound sequences, movies or even other VRML scenes. All aspects of virtual world display, interaction and internetworking can be specified using VRML. Using these possibilities 3D photo-models combined with VRML technology have a very broad applicability as for example distributed visualizations, interactive environments, interactive simulations for education, virtual museums, and more. If very large models have to be animated, VRML provides some possibilities to use different levels of resolution, depending on the distance and visibility of parts of the model to the current position of the user.

In addition also measurement tools (co-ordinates, orientations, distances, ...) can be added using the EAI (External Authoring Interface) (Zeisler Ph., 1999). This interface allows programmers to establish a connection between a web page and an embedded VRML browser window (Figure 4), thus providing a possibility to manipulate the VRML scene depending on user requests on the web page. Using this possibility the interactivity is not limited any more to the purely VRML scene but also external systems, as for example data bases, can be connected. In this way, the VRML model can be used as kernel of an interactive spatial information system (Dorffner L., 1999).



Figure 4. VRML visualisation and co-ordinate measurement tools using the EAI.

6 CONCLUSIONS

We have shown the applicability of the new helicopter system for architectural purposes. Because of the in-flight control system the operator knows exactly what the viewfinder of the photo camera sees. Thus almost every picture can be used for later evaluation.

Concerning the average root mean square errors both recording systems - analogue photographs using the model helicopter and digital terrestrial images - show to give the same good results: the accuracy achieved for both roof and facade points was estimated to be $\pm 2\text{cm}$ in average in all co-ordinate directions (Table 1). The flying height of the helicopter was between 40m and 80m. Using aerial images taken from aeroplanes such results, especially in height, would have been impossible under common circumstances.

The visualisation using VRML enables very easily the combination of different 3D models (facades and roofs of the mill) together with terrain models. The close connection of this data format to the internet further enables the possibility of showing the results to a great public.

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