EXPERIENCES WITH THE DIGITAL PHOTOGRAMMETRIC PROGRAM PACKAGE ORPHEUS BASED ON CIPA's "ZURICH CITY HALL" DATASET FOR ARCHITECTURAL PHOTOGRAMMETRY

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KEY WORDS: 3D Photo models, photogrammetric plotting, hybrid adjustment

ABSTRACT

It is the goal of this paper to describe a contribution to CIPA's Zurich test. The test project has been worked out using the PC-based digital photogrammetric program ORPHEUS. In order to show the flexibility and applicability of the program under quite general circumstances, several variants of both blocks were computed. After that, 3D photo models of the Zurich city hall were created. The results are reported, and the variants are compared to each other. The test blocks were additionally plotted using the widely used software package PhotoModeler in order to obtain a reference for comparison. The paper describes the main features of ORPHEUS, with emphasis on robust hybrid adjustment, the observation types which can be used and the work flow for the production of 3D photo models. Fictitious observations were applied for orientation/self-calibration (e.g., as horizontal and/or plumb lines) and for the 3D determination of points only being visible in one photograph. ORPHEUS is very flexible with respect to the control information which can be used. Another focus of the paper will be the presentation of the results of the Zurich blocks and a comparison of different variants of block computation.

1 INTRODUCTION

At the XVIIth CIPA Symposium in Olinda/Brazil a reference data set for testing and evaluating different software packages and tools of digital close-range photogrammetry for the purpose of heritage recording and documentation has been proposed (Streilein et al., 1999). The city hall of Zurich served as a test object. Two standard cameras were used for image acquisition, a Fuji DS 300 and an Olympus C1400L. These cameras record images of 1280 x 1024 pixels (Olympus) and 1280 x 1000 pixels (Fuji). Two sets images were taken to record the city hall. According to (Streilein et al., 1999), the focus was fixed during exposure. 21 well-distributed control points were measured using an reflectorless theodolite. In (Streilein et al., 2000), first experiences with the Zurich data set with four different software packages have already been presented. In this paper, we want to describe the experience gained in creating 3D photo models of the Zurich city hall from both the Olympus and Fuji data sets using the digital photogrammetric software ORPHEUS, and we want to confirm some of the results by comparing them to those obtained by using the software package PhotoModeler. In the following sections, we shall describe the properties of ORPHEUS and the way the Zurich city hall data set was handled. In section 4, the comparison to PhotoModeler will be made. Section 5 is dedicated to a conclusion and to an outlook on the future development of ORPHEUS.

2 ORPHEUS / ORIENT

The program ORIENT has been developed at the Institute of Photogrammetry and Remote Sensing at Vienna University of Technology (I.P.F.) since the mid-seventies. ORIENT is a specialist software for hybrid photogrammetric adjustment, characterised by its flexibility with respect to the observation types and geometric configurations which can be handled as well as by its professional presentation of the results of adjustment and by its capability of detecting gross errors in the data (Kager 1989). ORPHEUS, another development of the I.P.F., offers a graphical user interface to a part of ORIENT's functionality as well as a digital multi-image monocomparator for simultaneous interactive measurement of points and lines in multiple (terrestrial or aerial) digital images. ORPHEUS is especially designed for, but not restricted to, aerial triangulation for the generation of digital orthophotos, terrestrial photo triangulation with self-calibration of cameras, and the generation of 3D textured photo models.

2.1 The mathematical model of adjustment used by ORIENT

ORIENT offers the possibility of simultaneous hybrid least squares adjustment of many observation types, among others image co-ordinates, geodetic measurements, control points, model co-ordinates and fictitious observations of points belonging to polynomial surfaces and/or 3D curves (Kager 1989). Lately, the principle of fictitious observations has been expanded to implicit surfaces such as cylinders or spheres and to points being situated on contour lines of such surfaces (Kager 2000). Two techniques for gross error detection are offered: robust estimation and data snooping. In ORIENT, the observations are considered to be co-ordinates of points in 3D spaces.

A Cartesian *observation co-ordinate system* is attached to each of these spaces. These co-ordinate systems are related to the object co-ordinate system by mapping functions. The parameters of these mapping functions can be estimated from the observations by least squares adjustment.

The mapping functions: All observation types are treated in a unique way because, basically, for all observation types, the same mapping function is used to describe the relation between an observed point $p=(u,v,w)^T$ and its corresponding object point $P=(X,Y,Z)^T$:

$$\mathbf{p} - \mathbf{p_0}(\mathbf{adp}) = \lambda \cdot \mathbf{R}^T(\mathbf{\Theta}) \cdot (\mathbf{P} - \mathbf{P_0}) \tag{1}$$

In equation 1, $p_0 = (u_0,v_0,w_0)^T$ is called *interior reference point*. It can be modified by functions of the additional parameters **adp**. **R** is a rotational matrix depending on the rotational angles Θ, where Θ can be parameterised in various ways, e.g., $\Theta = (\omega,\varphi,\kappa)^T$. λ denotes the scale factor between the two co-ordinate systems. $P_0 = (X_0,Y_0,Z_0)^T$ is called *exterior reference point*. From equation 1, the specific mapping functions of all observation types are derived by giving specific interpretations to certain groups of parameters.

Image co-ordinates: For points observed in perspective images, the observation co-ordinate system corresponds to the camera co-ordinate system. In this case, $w = 0$ for all points. P_0 is the projection centre. $p_0 = (u_0,v_0,f)^T$ is the projection centre in the camera co-ordinate system, where $(u_0,v_0)^T$ is the principal point and f is the focal length. The additional parameters **adp** are the coefficients of polynomial functions modelling camera distortion. λ is no longer assumed to be constant for all points of a perspective image, but it describes the position of the object point P along the ray of projection. By using these assumptions and dividing the first two components of equation 1 by the third one, the well-known perspective equations are obtained (Kager 1989).

"GESTALT" (shape) observations: GESTALT observations are fictitious observations of points P being situated on a surface in object space. These surfaces are also modelled in a local co-ordinate system related to the object co-ordinate system by equation 1. In this case, the scale is supposed to be constant: $\lambda = 1$. In order to model P as being situated on a surface, P 's distance from the surface can be fictitiously "observed" to be 0. In ORIENT, the greatest component of the difference vector is used as an observation instead of the Euclidean distance. p_0 receives a special interpretation: its components are modelled to be polynomial functions of two components of $p_R = (u_R,v_R,w_R)^T = R^T \cdot (P - P_0)$. By each of those polynomial functions, a surface is modelled in the (local) observation co-ordinate system, so that the mapping function for a GESTALT observation can, for instance, be formulated as follows:

$$u = 0 = u_R + \sum_{j,k=0}^{n,n} a_{jk} \cdot v_R^j \cdot w_R^k \tag{2}$$

In equation 2, the additional parameters **adp** from equation 1 are replaced by the GESTALT coefficients a_{jk}, which describe the shape of the surface in the observation co-ordinate system. GESTALT observations can be formulated for v and w in a similar way. Within an application, an arbitrary subset of all possible coefficients can be selected for modelling a certain GESTALT. As the parameters of the mapping functions are assigned to the GESTALTs by reference, it is possible to let more than one GESTALT of different coefficients refer to the same observation co-ordinate system, and it is also possible to let several GESTALTs share the same coefficients, but refer to different observation co-ordinate systems. In this way it is possible to implicitly model geometrical constrains between surfaces (Kager 1989).

Other observation types: For all other observation types handled by ORIENT, the mapping functions can be derived from equation 1 by re-interpretation of parameters in a similar way (Kager 1989).

Hybrid parameter estimation: The mathematical model of adjustment is given by the specialisations of the mapping functions described in the previous section. The stochastic properties of the observations are considered by substituting the observed points p by their expectations $E(p) = p + r$, r being the vector of residuals of p. The stochastic model of adjustment in ORIENT is described by the assumption of uncorrelated and normally distributed observations. The user is free to decide which parameters are to be determined in adjustment and which parameters are considered to be constant. However, care has to be taken to avoid dependencies between parameters in order to avoid singularities. Gross errors in the observations can be detected by robust estimation. For that purpose, iteration is continued after adjustment has been terminated, this time the weights of the observations being modulated in dependence of the normalised residuals of the most recent iteration (Kager 1989).

2.2 Interactive measurement of points and lines in images and definition of GESTALT observations

The principle of measuring points in digital images using ORPHEUS is depicted in figure 1. Several images are visualised simultaneously on the screen. The points and lines already having been measured are superimposed to the images. For each image, an overview as well as a zoom window is provided, the latter being positioned by pressing 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. A point is measured by pressing the left mouse button either in the overview or in the zoom window. There are several modes of point measurement which differ by the way the point identifier is incremented. These modes correspond to plotting modes such as measuring all points in one image or transferring points from one image to the other ones. In the "point transfer" mode, epipolar lines can be used to support point identification in the other images. Lines can be defined to connect a point pair by snapping both end points or by a special point

measurement mode connecting the points in the order they are measured. In figure 1, a window representing a GESTALT is open. The GESTALT has no graphical representation, but the points contained in it are highlighted in all open images. Thus, GESTALT 3003 in figure 1 is a vertical straight line corresponding to the edge of the building. No homologous points have to be found: the parameters of the straight line (the coefficients of the polynomial function in equation 2) are determined by intersection of bundles of rays in hybrid adjustment. By measuring/deleting a point in this situation, the point will also be inserted to/deleted from all open GESTALTs.
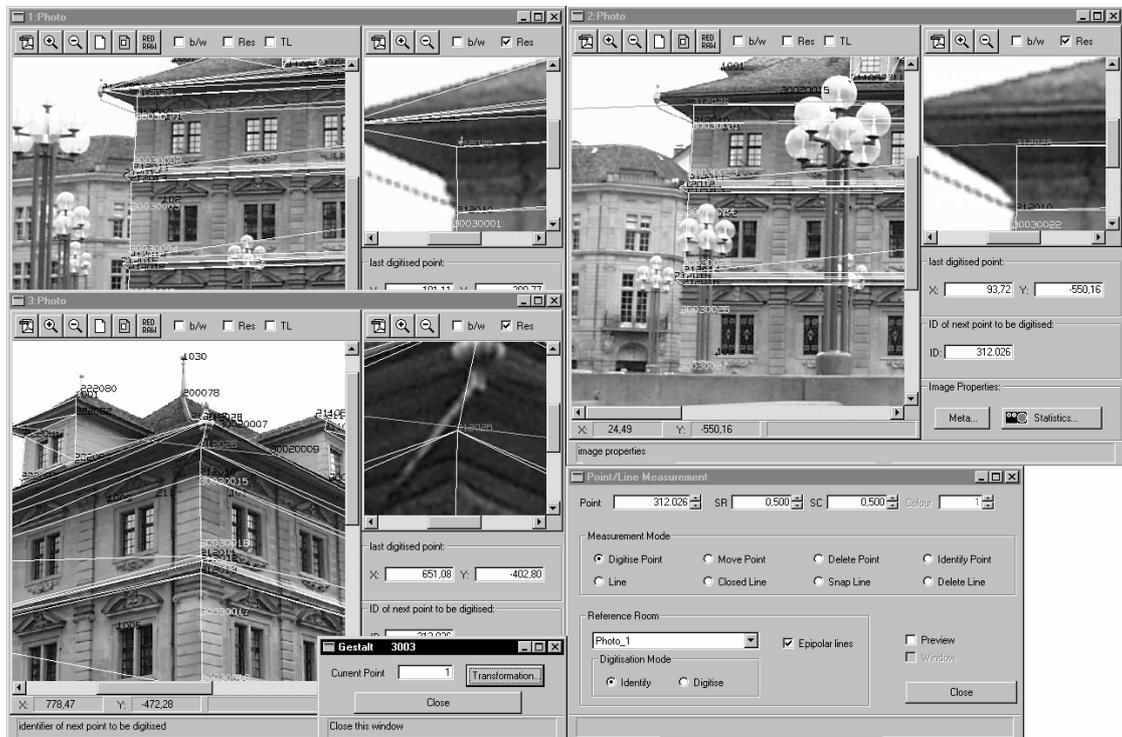

Figure 1: Interactive measurement of points and lines using ORPHEUS.

2.3 Work flow for the generation of 3D photo models

The work flow for the generation of a 3D photo model using ORPHEUS basically consists of four stages: (1) data import, (2) orientation of the images, (3) creating the geometrical model, and (4), mapping the texture to the geometrical model to create the 3D Photo model. In principle, an arbitrary number of images taken with an arbitrary number of cameras can be used in this work flow.

Data import comprises the import of control points from ASCII files, the import of images (JPEG or TIFF files), the generation of image pyramids for the visualisation of large images and the import of camera data from calibration protocols. For the latter purpose, the polynomial coefficients describing camera distortion have to be estimated from the distortion tables provided by the camera manufacturer.

Orientation of the images: For scanned analogue images, the fiducial marks have to be measured to reconstruct inner orientation. For computing outer orientation, both control and tie points have to be measured in the images, and GESTALT observations can be defined. Approximate values for the rotation angles have to be provided either by an automatic spatial resection using at least four points of known object co-ordinates, or by applying a graphical tool for positioning the axes of the camera co-ordinate systems of all photos in a ground plot of the object co-ordinate systems. If self-calibration is to be applied, approximate values for the focal lengths of the cameras involved have to be provided. After that, hybrid photogrammetric adjustment is used to determine all unknown mapping parameters and the object co-ordinates of all control and tie points. In this context, the user has every freedom with respect to the control information which is to be used to define the geodetic datum of the block. Control points can be used as "observed object co-ordinates", but it is also possible to directly use theodolite measurements instead of control points, or to use GESTALTs for modelling plumb/horizontal lines to level the block and import distance measurements for determining the scale. A residual plot in the images can be used to correct the errors detected by robust estimation. The stochastic model of adjustment can be checked by variance component analysis. It is possible to mix self-calibration of amateur cameras with metric cameras. At any instance, the mathematical model of camera distortion can be changed, cameras can be re-assigned to photographs, and adjustment can be repeated.

Creating the geometrical model: Using the interactive measurement tools of ORPHEUS, a wire frame model of the object can be created by measuring the relevant object vertices and defining lines between these vertices. In the current version, it is necessary to define

these lines in a way to create triangles so that several conditions are fulfilled: (1) each part of the object has to be covered exactly by one triangle, (2) these triangles must not intersect, (3) there must not be three triangles sharing a common edge, and (4), for each triangle there has to be at least one image where all its vertices have been measured. As soon as all object vertices have been measured in the images, their object co-ordinates are determined by spatial intersection, and a boundary representation (B-rep) is created by finding closed triangular loops in the wire frame model. Contradictions to the rules described above are reported, and the triangles involved are discarded. Neighbouring co-planar triangles are merged to closed polygons. The resulting B-rep model is exported in the VRML format (Carey and Bell 1997). Errors can be corrected according to a visual inspection. GESTALTs can be used for determining points only visible in one image. The creation of the geometrical model is terminated by a final overall adjustment of all available observations.

Texture mapping: As soon as a consistent geometrical model has been generated, texture from the digital images is projected to the faces of the B-rep. In ORPHEUS, the "optimal" photo is being searched for, i.e., the photo with a viewing direction closest to the normal vector of the face (Dorffner and Forkert 1998). This selection can be overridden by the user after a visual inspection of the photo model. Eventually, contrast enhancement tools can be applied to improve the visual appearance of the photo model created in the VRML format.

3 HANDLING THE ZURICH CITY HALL DATA SET USING ORPHEUS

3d photo models of the Zurich city hall were created from both the Fuji and the Olympus data sets using ORPHEUS. From the Olympus data set, all available photos were used. With respect to the Fuji data set, images 2 and 3 were left aside. The camera distortion coefficients were estimated from the distortion tables given in (Streilein et al. 1999).

3.1 Orientation of the images

Two variants of the block were computed for each of the two data sets, both making use of the control points for the determination of the geodetic datum of the blocks. In the first variant, the parameters of inner orientation and lens distortion presented in (Streilein et al. 1999) were used as constants. The second variant included self-calibration of the cameras. With respect to the Olympus data set, a third variant was computed to show how the geodetic datum can be determined just from the definition of plumb lines and from measured distances.

3.1.1 Interactive measurement

The control points and well-distributed tie points were measured in all images in the way described in section 2.2. With respect to the tie points, care was taken to select points visible in at least three images. Some of these points were chosen outside the facades of the buildings in order to achieve a good point distribution for self-calibration. For the variants with self-calibration, four GESTALTs corresponding to the four vertical building edges were introduced, and for each of these GESTALTs, about five points per image were measured (figure 1). As each of these points gives four observations (two GESTALT equations because a line is considered to be the intersection of two planes, and two image co-ordinates), but only adds three new unknowns to adjustment (its object co-ordinates), each point thus measured increases redundancy by one. With the Olympus data set, two additional GESTALTs corresponding to the gutter edges of the east and west facades were introduced as horizontal straight lines. Besides of the "block points" (control and tie points) and the GESTALT points, the modelling points were also measured. Note that these categories of points are not distinguished in ORPHEUS in principle; the distinction is just given by the user, e.g. by selecting different a priori r.m.s. errors for different point sets, or by applying a certain numbering scheme. GESTALTs were also introduced for modelling in order to determine points on single rays (section 3.1.3).

3.1.2 Photogrammetric adjustment

All the observations described in section 3.1.1 were simultaneously adjusted using the bundle block solution of ORIENT. For each of the variants described above, robust estimation and data snooping were carried out to eliminate gross errors. A variance component analysis was applied to improve the stochastic model of adjustment. After changing the stochastic model, error detection had to be repeated.

Geodetic datum: For four of the variants, the geodetic datum was to be derived from the control points which are part of the data set. Performing robust estimation, it was found out that there were contradictions between the control points from different facades. It became obvious that the control points were not given in a unique co-ordinate system: the facades appear to be shifted with respect to each other. Thus, only the points 101-113 from the west facade were introduced as control points, the other points remaining in the block as tie points. Under these assumptions, the average vectors of discrepancies are (0.24 / 1.38) [m] for points 201-212, and (-0.82 / -1.05) [m] for points 301-323, the exception being point 311 which has obviously false planimetric co-ordinates in the data set. The residuals are not exactly constant over a facade, which might be caused by a false interpretation of the control point sketch in the data set description, but the average size of the residuals strongly indicates a systematic shift. The new co-ordinates of control points 201-323 are given in table 1.

With respect to one variant of the Olympus data set, only distances were used instead of control points to define the geodetic datum of the block. The distances between points 101 and 111, 111 and 121, 101 and 121, and between 301 and 321 were computed from the co-

ordinates of these points (these are the distances which could be easily measured using a tape). They were used to define the scale of the block. The four vertical lines at the building edges corresponding to four GESTALTS (cf. section 3.1.1) were used to define the vertical axis and, thus, also to define two rotations of the block (ω and ϕ). In order to determine the shift of the block, point 101 was introduced as a control point. In order to determine the third rotation (κ) of the block, the y co-ordinate of point 121 was introduced as a "control co-ordinate". Note that the four (3+1) co-ordinates of these two points are just used to avoid singularities of the block.

Point	201	202	211	212	301	302	303	311	312	321	322	323
X	114.93	114.99	116.31	116.30	150.08	150.06	150.00	132.24	132.26	116.33	116.31	116.42
Y	249.06	248.99	237.22	237.25	255.11	255.12	255.12	252.96	252.99	251.15	251.16	251.17
Z	14.68	3.65	14.67	3.64	14.72	10.42	3.72	14.68	8.30	14.68	10.38	3.69

Table 1: New co-ordinates of points 201-323 as derived from photogrammetric triangulation (Olympus data set). The r.m.s. errors of these co-ordinates are ±4.5 cm (X, Y) and ±3 cm (height), which is in accordance with measurements from a reflectorless theodolite.

Self-calibration: In order to perform self-calibration, the parameters of inner orientation as given in the data set description were used as approximate values. The co-ordinates of the principal point were introduced as observations with an an priori r.m.s. error of ±10 pixels. Several variants were computed using different parameterisations of the distortion polynomial. Initially, all images were given identical, but unknown parameters of inner orientation and distortion. There were no contradictions to this assumption in the Fuji data set. However, performing robust estimation in the Olympus data set, it was obvious that the tie points not being situated in the facades were eliminated as gross errors even though they were obviously correct. This observation and the fact that the distribution of residuals appeared to be systematic initiated the suspicion that some of the photos might have been taken using another focal length. Adjustment was repeated using individual parameters of inner orientation and distortion for all images. Of course, these parameters were determined rather badly (typically, the r.m.s. error of the focal length was ±50 pixels), but the results could be used to find hypotheses about groups of images having identical parameters. In an iterative procedure, groups of images were declared to have identical parameters of inner orientation and distortion if the results of self-calibration did not differ significantly. Two groups of images with different inner orientation parameters remained: Images 1-5 and 12-16 have been taken with a focal length of 1334 pixels, and images 6-11 (those showing the east facade) with a focal length of 1572 pixels. The distortion polygon for modifying the components (u_0,v_0) of $\boldsymbol{p_0}$ in equation 1 depending on the co-ordinates of the principal point (u_{pp},v_{pp}), the reduced image co-ordinates $\bar{u}$ and $\bar{v}$ and the polynomial coefficients (the distortion parameters) a_i is given by equation 3:

$$\binom{u_0}{v_0}=\binom{u_{pp}}{v_{pp}}+\left[\begin{array}{c} a_3\cdot\bar{u}\cdot(r^2-1)+a_4\cdot\bar{u}\cdot(r^4-1)+a_5\cdot(r^2+2\cdot\bar{u}^2)+a_6\cdot(2\cdot\bar{u}\cdot\bar{v})+a_{37}\cdot\bar{u}\cdot(r^6-1)+a_{38}\cdot\bar{u}\cdot(r^8-1) \\ a_2\cdot\bar{v}+a_3\cdot\bar{v}\cdot(r^2-1)+a_4\cdot\bar{v}\cdot(r^4-1)+a_5\cdot(2\cdot\bar{u}\cdot\bar{v})+a_6\cdot(r^2+2\cdot\bar{v}^2)+a_{37}\cdot\bar{v}\cdot(r^6-1)+a_{38}\cdot\bar{v}\cdot(r^8-1) \end{array}\right] \quad (3)$$

with $\bar{u}=\dfrac{u-u_{pp}}{\rho_0}$, $\bar{v}=\dfrac{v-v_{pp}}{\rho_0}$, and $r^2=\bar{u}^2+\bar{v}^2$. ρ_0 is the normalisation radius; it is the radius of a circle of zero distortion.

In equation 3, a_2 corresponds to a scale of the v-axis, a_3, a_4, a_{37} and a_{38} describe a radial component of distortion, and a_5 and a_6 describe an asymmetric distortion component. Table 2 shows the values for the distortion parameters, the principal point (u_{pp}, v_{pp}) and the focal length f for all variants as well as the theoretical r.m.s. errors σ of these parameters from self calibration.

Camera	u_{pp} [pixel]	v_{pp} [pixel]	f [pixel]	a_2	a_3	a_4	a_5	a_6	a_{37}	a_{38}	ρ_0 [pixel]
Oc	610.4	-495.5	1334.3	-	15.135	-22.628	-	-	14.564	-3.398	621.0
Of I	624.2	-481.3	1334.0	-2.012	-27.386	0.196	0.503	-0.713	-	-	621.0
σ	±4.5	±4.5	±3.0	±0.45	±2.1	±1.6	±0.36	±0.36	-	-	-
Of II	608.6	-480.7	1572.3	1.082	-18.784	4.557	-0.497	-0.016	-	-	621.0
σ	±4.7	±4.8	±3.1	±0.42	±1.8	±1.1	±0.32	±0.32	-	-	-
Fc	651.9	-511.1	1260.0	-	0.00075	0.00006	-	-	-	-	605.8
Ff	637.1	-482.2	1254.5	0.887	-28.504	6.558	0.533	0.230	-	-	605.8
σ	±4. 6	±4.5	±1.8	±1.9	±0.95	±0.65	±0.38	±0.35	-	-	-

Table 2: The parameters of inner orientation. Oc, Fc: Olympus / Fuji, calibration from the data set description. Of I, Of II: the parameter sets for the Olympus data set derived by self-calibration. Ff: the results of self calibration for the Fuji data set.

Comparison of variants: The results of adjustment for the five variants are compared in table 3. Note that in each variant, variance component analysis has been used to achieve a realistic stochastic model. Thus, the a priori r.m.s. errors of the image co-ordinates indicate how well the mathematical model of adjustment fits to the data. It can be seen that with the Olympus data set, the r.m.s. error of an observed image co-ordinate was ±2.0 pixels and, thus, worse by a factor of two than with the variants using self calibration, which results in worse r.m.s. errors of the computed object points. In addition, more observations had to be eliminated in that version. It can be clearly seen that by applying self calibration with two sets of inner orientation, the accuracy of the Olympus block could be increased significantly. The same statement holds true for the Fuji block. Comparing the Olympus and the Fuji blocks, it can be said that the Olympus block is a little more accurate. By applying self calibration, a theoretical accuracy of ±4 cm can be achieved using the cameras and the image configurations of the test data set.

Block	CP	Calibration	N_{obs}	N_{unk}	N_{elim}	σ_b [pixel]	σ_m [pixel]	σ_g [pixel]	σ_0	σ_{xyz} [cm]
Olympus	101-123	No	1714	701	33	±2.0	±2.0	-	±1.0	±8.3
Olympus	101-123	Yes	2618	1360	11	±0.8	±1.0	±0.7	±1.0	±3.8
Olympus	None	Yes	2583	1360	22	±0.8	±0.8	±0.8	±1.0	±3.9
Fuji	101-123	No	1248	633	6	±1.5	±1.5	-	±1.0	±9.8
Fuji	101-123	Yes	1823	1078	7	±0.6	±1.0	±0.5	±0.9	±4.3

Table 3: Comparison of the results of the five variants of the block. CP: the identifiers of control points used for the definition of the geodetic datum of the block. N_{obs}, N_{unk}, N_{elim}: Numbers of observations, unknowns, and observations eliminated by robust estimation, respectively. σ_b, σ_m, σ_g: a priori r.m.s. errors of an observed image co-ordinate of a "block" (control or tie), a "model", and a "gestalt" point, respectively. These r.m.s. errors were obtained from a variance component analysis. σ_0: r.m.s. error a posteriori of the weight unit. σ_{xyz}: average r.m.s. error of a point's object co-ordinate in [cm].

3.2 Creating the model

The model was created for both the Olympus and the Fuji data sets using the adjustment variants with self calibration and control points. With respect to the Olympus data set, a slightly higher level of detail was chosen by also modelling the ledges on the facades at each floor. On the west and south facades, the dormers could almost be modelled completely. The missing points could be reconstructed by assuming similarity constraints. In some cases, GESTALTs were used to reconstruct points only visible in one image. Figure 2 shows such a case: point 244119 was only visible in image 6 of the Olympus block. In order to make it determinable, a GESTALT corresponding to a vertical wall was created, and points 244103, 244104, 244106, and 244119 were added to it. As points 244103, 244104, and 244106 were visible in more than one image, the surface parameters could be determined, whereas point 244119 was determined from intersection of one image ray with that surface. These operations ("determine surface parameters", "intersect surface and image ray") are not performed as individual steps, but they are just an integral part of hybrid adjustment by providing certain sets of additional observations and unknowns.
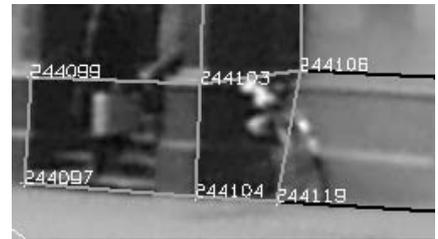

Figure 2: a vertical plane was used to determine point 244119.

Figure 3: Two views of the model created from the Olympus data set.

For the North and East facades, it was not possible to completely reconstruct the dormers on the roof. It was also impossible to add photo-realistic texture to the roof so that the roof was only reconstructed geometrically. Figure 3 shows two views of the photo model created from the Olympus data set. The left part shows the "good" facades where all dormers could be reconstructed and the visual impression of the model is quite good. On the other facades, there were problems with reconstructing the dormers, and texture mapping in the entrance region was not very well because there was only one image taken from a very oblique angle. With respect to the Fuji model, it was important to use contrast enhancement tools because some of the images were rather dark.

4 COMPARISON TO PHOTOMODELER

It is not the aim of this section to present detailed experiences using the CIPA reference data set with the PhotoModeler software package, but rather to report about comparable results obtained with this widely used commercial package, taking into account results from ORPHEUS. A survey based on CIPA's Zurich test with the version 3.1 of PhotoModeler has been presented in (Streilein et al., 2000). A test block processed with the latest version 4.0 and combining 29 images from the Fuji and the Olympus data sets is described below.

4.1 Main features of PhotoModeler

PhotoModeler (EOS, 2001) has several groups of users involved in close range applications, not only specialists in photogrammetry but also architects, archaeologists and even designers who use the opportunity for creating 3D objects out of simple 2D photos. This software product calculates measurements and constructs 3D models from different kinds of photographs. A general bundle solution is used with almost no limits to the number of photos and points. Eos' bundle adjustment provides camera self-calibration and full error propagation. The first stage provides automated relative and absolute camera orientation. A so-called "Global Optimisation" adjusts the positions and angles of the camera stations and the positions of the points on each iteration, and minimises the errors found in the input data to come up with the best solution for camera stations and 3D object points.

The changes in version 4.0 make the package even more user-friendly and include several new possibilities in the different steps of orientation, the measuring process, reconstruction and export of data. There are four major new items concerning the orientation of the images and the reconstruction of the object. First, a new type of object called an "edge" has been added. Edges are like lines, but they do not have distinct end points. They are also processed in global optimisation in the way points are. Second, new capabilities for constraining the relationships between objects have been added. Third, another new type of object called a "curve" has been added. These objects are marked and referenced across photographs like points, edges, and cylinders, but are not computed in global optimisation. Fourth, new capabilities for handling single photo projects were provided: in Pro 3.1 a single photo could be handled only if it had control points; in Pro 4.0, the user can draw lines, edges and surfaces on a single photo, and by specifying certain types of co-ordinate system constraints on those lines, edges and surfaces, the camera orientation and full xyz data for the points and edges can be processed. More information about these items as well as other special features are given in detail at (EOS, 2001).

4.2 Measurements and constraints

The principle of measuring points in digital images using PhotoModeler (figure 4) is comparable to ORPHEUS. Measurements are done in a mono-comparator mode, measurement and referencing between photos is done manually, with the help of epipolar lines or auto-drive referencing (a form of semi-automated referencing). In this last mode, when the source and destination images are oriented, the cursor and image will automatically jump to the expected location of the point in the destination image, allowing the execution of the final measurement.
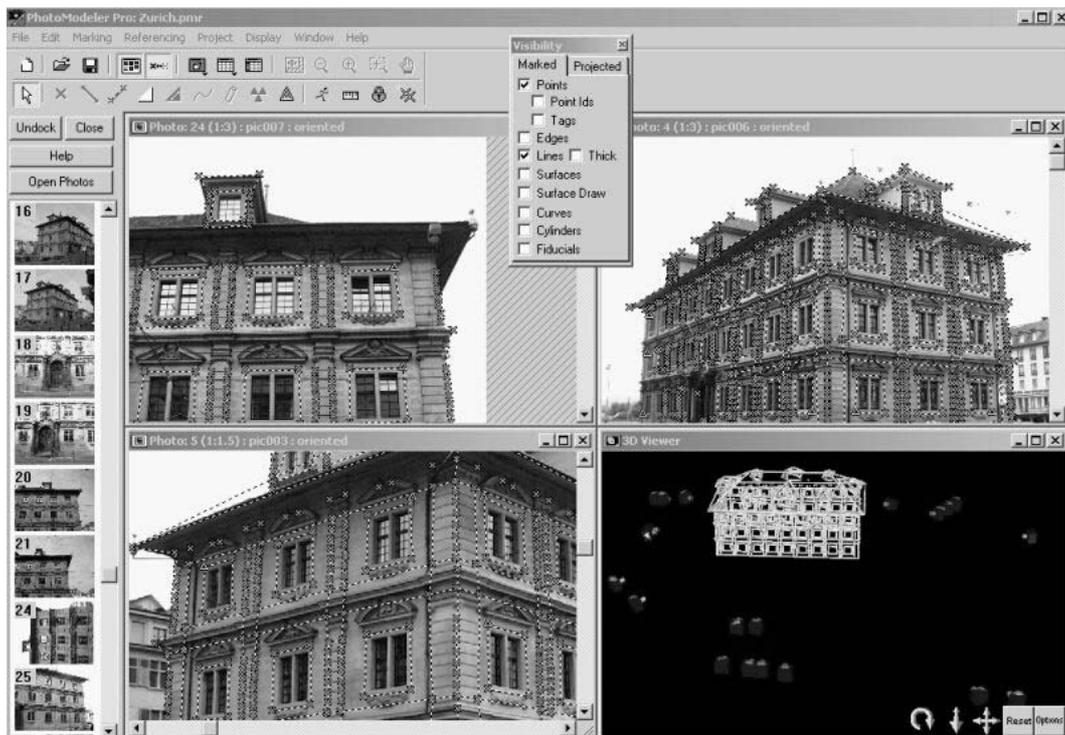

Figure 4: Measurement of points and lines, and visualization of the wire frame model using PhotoModeler

Additional information called "constraints" can be defined. There are three main categories of constraints in PhotoModeler: multi-photo constraints, axes constraints, and control point constraints. In version 4, new functions are available: constrain the distance between two points to a given value, constrain points to fit on a plane, constrain two lines to be perpendicular or to intersect at a given angle, constrain

lines or edges to have the same length or to be parallel, constrain two edges to intersect or constrain an edge to intersect a point. These constraints can be compared to GESTALTs in ORPHEUS, which, however, offers more possibilities for defining fictitious observations.

The steps of the work flow for the generation of 3D photo models described in section 2.2 are the same for both software packages. The progress and reliability of the restitution is visualised by a 3D-viewing tool using the Windows Direct3D interface. Orthophotos of complex surfaces can be produced and exported as bitmaps. The export formats for the spatial result are wide-spread and include DXF, 3D-Studio, VRML and some others.

4.3 Remarks about photogrammetric adjustment

The user interface of the adjustment module is prepared for being used by non specialists. Only a few parameters can be defined by the user. Termination parameters for optimisation (such as maximum iteration, solution tolerance), default point standard deviation weights in pixels and self calibration or field calibration parameters can by changed in the preferences interface. The processing of the block of photographs follows three steps : exterior orientation, global optimisation and self calibration (optional). No details are given about the algorithms in use, but several accuracy studies have confirmed the robustness of the bundle software (EOS, 2001). Problems may occur when the adjustment process fails, and the lack of robust estimation and data snooping to eliminate gross errors (as available in ORPHEUS) makes the processing difficult when several control points are doubtful. The complementary use of ORIENT's adjustment module was very helpful in our example.

In Photomodeler, the factors of quality given by the software for each point are: precision in (X, Y, Z), numbers of photos, tightness (a value used to indicate the accuracy of an object point's photo markings), angle (between the photographs that image an object point), constraints. The user has to analyse this factors in order to obtain a reasonably good solution, and if necessary to try different solutions.
The project computed with Photomodeler was based on 29 photographs from both cameras. The false planimetric coordinates of point 311 have been confirmed. The final solution has been processed by fixing points 101-113 only, as proposed in paragraph 3.1.2 and the same conclusions have been verified.

5 CONCLUSION

It has been shown that both blocks of the Zurich city hall data set could be handled successfully using ORPHEUS/ORIENT. The tools for error analysis provided by this software package turned out to be well-suited for applications in architectural photogrammetry, and they were capable of detecting "hidden" errors in the original data set which had not been detected yet: The control point co-ordinates of the data set were detected to contain gross errors, and it was found out that the Olympus images were taken with two different focal lengths. These results were confirmed by the photogrammetric package PhotoModeler. With respect to the creation of 3D photo models, ORPHEUS could be used without problems, and the principle of using GESTALTs for the determination of points on single rays was applied successfully. Future work will concentrate on improving the work flow of geometric modelling in ORPHEUS: currently, a certain overhead in the work flow is caused by ORPHEUS being restricted to triangular faces. This restriction will be eliminated by a new module for editing polygons in the next release. Of course, the questionnaire provided by the authors of the Zurich city hall data set was filled in with respect to ORPHEUS. Persons who are interested in it are encouraged to contact the authors by e-mail.

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